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SUMMARY

The results of bending vibration tests on 1/40-scale dynamic models of the Saturn V launch vehicle and its umbilical tower are presented herein. The lateral vibratory response characteristics of these structures, considered separately and as an integral configuration mounted on the launch platform, are presented. Mode shapes, resonant frequencies, and damping values were determined over a frequency range of 10 to 300 hertz (0.25 to 7.5 hertz, full-scale equivalent). The results include data for two simulated mass conditions corresponding to a fueled and an unfueled launch vehicle. A description of the models is presented and the scaling concepts employed in their design are discussed.

The first four cantilever modes and frequencies of the 1/40-scale models of the vehicle and tower are presented. At its first resonance, the tower responds in planes which are not coincident with its planes of symmetry. The test results for the complete configuration indicate considerable coupling between the launch vehicle and the tower at the higher frequencies, but little coupling at the lower frequencies (below 60 hertz) even though the first cantilever modes of the vehicle and tower were included in this low-frequency range.

INTRODUCTION

The Langley Research Center has undertaken programs to determine the ability of dynamically scaled models of launch vehicles to duplicate full-scale-vehicle structural dynamic properties. These investigations have established the feasibility of using models to obtain vibration data at much less expense than required to obtain the same data from full-scale vehicles and also have provided useful information for the evaluation of analytical studies performed on these structures. For example, reference 1 shows good agreement between experimental vibration characteristics obtained from a full-scale Saturn SA-1 launch vehicle and a 1/5-scale replica model. Similarly, reference 2 uses vibration data obtained on a scaled model of an operational vehicle to illustrate the use of model data to validate dynamic analysis procedures. The full benefit derived from the use of dynamically scaled models of flight vehicles (for some other examples, see ref. 3) is immeasurable when one considers the relative cost and effort required for a full-scale ground vibration survey.

The mobile launcher concept for the Apollo Saturn V launch vehicle is a new approach in the preparation of a space vehicle for flight. The basic concept is to erect the launch vehicle in a sheltered environment on a launch platform with umbilical tower. Here, in a sheltered environment, integrated tests of the completed space vehicle are performed, followed by a mission simulation test of an actual countdown. The Saturn V launch vehicle, joined with the launch umbilical tower, is then transported 3 miles (5 kilometers) to the launch pad in a near-launch-ready state, with all umbilical connections intact. The sizes of these structures are enormous; the entire configuration weighs 6000 tons (5 443 200 kg), and the launch vehicle and its umbilical tower stand 361 feet (110 meters) and 381 feet (116 meters), respectively, on the launch platform. These unique features of the Saturn V—launch-umbilical-tower (Saturn V-LUT) configuration, namely, (1) its tremendous size and (2) the requirement for mobility, lead to the possibility of severe static and dynamic problems which require investigating. Dynamic coupling between the launch vehicle and its umbilical tower is one such area of interest. Because of the sizes of the structures involved, it is only natural to consider the use of a reduced-scale model to predict the vibration characteristics of this configuration.

The purpose of this report is to present the results of an experimental investigation of the bending vibration characteristics of a 1/40-scale dynamic model of the Apollo Saturn V-LUT configuration. This investigation is a continuation of the Langley Research Center work on the evaluation of dynamic modeling technology for adequately defining vibration characteristics of full-scale structures. The configuration is comprised of models that simulate the mass and stiffness distributions of the full-scale hardware. However, scale factors were modified from those which would have been obtained by strict geometric scaling in order to satisfy the fabrication requirements; thus, equivalent values of mass and stiffness were established. The results reported herein were employed to facilitate an analytical investigation of the same configuration, and a comparison of the analytical studies with the test results is given in reference 4.

SYMBOLS

E	Young's modulus, pounds force/inch^2 (newtons/centimeter^2)
f	frequency, hertz
G	acceleration of gravity, 32.2 feet/second^2 (9.8 meters/second^2)

g	damping factor, $\frac{1}{n\pi}\log_e\left(\frac{x_o}{x_n}\right)$
I	area moment of inertia, inches^4 (centimeters^4)
l	characteristic length, inches (centimeters)
m	mass, pounds force-second^2/inch (kilograms)
n	number of cycles used in determining damping factor g
t	skin thickness, inches (centimeters)
X,Y	reference axes
x,y	directions of excitation
x_o	initial vibration amplitude, inches (centimeters)
x_n	vibration amplitude after n cycles, inches (centimeters)
ρ	mass density, pounds mass/inch^3 (kilograms/centimeter^3)

Subscripts:

FT	full-scale tower
FV	full-scale launch vehicle
MT	model of tower
MV	model of launch vehicle

1/40-SCALE SATURN V-LUT CONFIGURATION

Scaling

The 1/40-scale models of the Saturn V launch vehicle and its launch umbilical tower (LUT) were constructed to investigate vibration characteristics of the prototype structures and to advance the technology of dynamic modeling. The theory of models and dimensional analysis is presented in reference 5. Important parameters simulated in scaling were mass and stiffness magnitudes and distributions.

All linear dimensions of the vehicle could not be geometrically scaled because of limitations in fabricating very thin materials; thus, the scaled values of skin thickness were increased by a factor of 4. Because the Saturn V model was constructed of magnesium instead of aluminum primarily used in the full-scale vehicle, its skin thickness was increased by an additional factor of 1.54 to compensate for the difference in the modulus of elasticity. In order for the bending frequencies to scale directly with the scale factor (1/40), the scaled values of the nonshell mass properties of the model also were increased by a factor of 4.

In addition, complicated structural parts of the vehicle, such as composite or stringer elements, were simulated by simplified structural elements having equivalent stiffness and mass properties. For example, the honeycomb structure of the lunar-module adapter was simulated with a sheet of magnesium supported with a layer of balsa wood; also, the number of stringers and the stringer thickness were varied from full-scale details to obtain the desired scale value of stiffness.

Steel was used in both the full-scale and the 1/40-scale LUT. Thus, the modulus-of-elasticity ratio for the LUT was unity.

From these considerations, the following scale factors were defined:

Length:

$$\frac{l_{MV}}{l_{FV}} = \frac{l_{MT}}{l_{FT}} = \frac{1}{40}$$

Modulus of elasticity:

$$\frac{E_{MV}}{E_{FV}} = \frac{1}{1.54}; \quad \frac{E_{MT}}{E_{FT}} = 1$$

Density:

$$\frac{\rho_{MV}}{\rho_{FV}} = \frac{1}{1.54}; \quad \frac{\rho_{MT}}{\rho_{FT}} = 1$$

Skin thickness:

$$\frac{t_{MV}}{t_{FV}} = 4(1.54)\,\frac{l_{MV}}{l_{FV}} = 4(1.54)\left(\frac{1}{40}\right); \quad \frac{t_{MT}}{t_{FT}} = 4\left(\frac{l_{MT}}{l_{FT}}\right) = 4\left(\frac{1}{40}\right)$$

Mass:

$$\frac{m_{MV}}{m_{FV}} = 4\left(\frac{\rho_{MV}}{\rho_{FV}}\right)(1.54)\left(\frac{l_{MV}}{l_{FV}}\right)^3 = 4\left(\frac{1}{40}\right)^3; \quad \frac{m_{MT}}{m_{FT}} = 4\left(\frac{\rho_{MT}}{\rho_{FT}}\right)\left(\frac{l_{MT}}{l_{FT}}\right)^3 = 4\left(\frac{1}{40}\right)^3$$

Cross-section moment of inertia:

$$\frac{I_{MV}}{I_{FV}} = 4(1.54)\left(\frac{l_{MV}}{l_{FV}}\right)^4 = 4(1.54)\left(\frac{1}{40}\right)^4; \quad \frac{I_{MT}}{I_{FT}} = 4\left(\frac{l_{MT}}{l_{FT}}\right)^4 = 4\left(\frac{1}{40}\right)^4$$

Bending frequency:

$$\frac{f_{MV}}{f_{FV}} = \left[\frac{E_{MV}I_{MV}}{E_{FV}I_{FV}}\frac{m_{FV}}{m_{MV}}\left(\frac{l_{FV}}{l_{MV}}\right)^3\right]^{1/2} = 40; \quad \frac{f_{MT}}{f_{FT}} = \left[\frac{E_{MT}I_{MT}}{E_{FT}I_{FT}}\frac{m_{FT}}{m_{MT}}\left(\frac{l_{FT}}{l_{MT}}\right)^3\right]^{1/2} = 40$$

Model Description

A photograph of the 1/40-scale dynamic model of the Saturn V—launch-umbilical-tower (Saturn V-LUT) configuration is shown in figure 1 and a sketch of the configuration showing pertinent dimensions and nomenclature used herein is presented in figure 2. The configuration is made up of the following parts: (1) a 1/40-scale dynamic model of the Saturn V vehicle and (2) a 1/40-scale dynamic model of the launch umbilical tower (LUT) consisting of the tower and platform.

Saturn V launch vehicle.- The 1/40-scale model of the Saturn V vehicle consists of components representing the three booster stages and of a payload section that includes models of the lunar module (LM), service and command modules, and the launch escape system. The 1/40-scale dynamic model of the Saturn V launch vehicle is 109.8 inches (278.9 cm) in length, measured from the model tip to the bottom of the first-stage engines, and has a maximum diameter of 9.9 inches (25.15 cm). The model has a mass of 326.54 pounds (148.12 kg) when fully ballasted; however, the first stage is only 85 percent full because it was equipped with mechanical slosh simulators. The space required for the proper operation of these slosh simulators limited the amount of propellant in the first stage to 85 percent of the full condition. A cross-sectional sketch of the 1/40-scale Saturn V model is shown in figure 3. Measured mass and calculated bending stiffness distributions of the Saturn V model are presented in figures 4 and 5, respectively. The stiffness distribution of the full-scale Saturn V vehicle shown in figure 5 was obtained from unpublished results of a vibration analysis of the full-scale Saturn V vehicle performed at the George C. Marshall Space Flight Center. Basically, the present model consists of a stack of flanged, cylindrical shells bolted to one another; within this shell the various thrust structures, simulated bulkheads, and propellant loads are located at the appropriate stations along the length of the model. Details of a typical flanged joint are shown in figure 6(a).

The engines incorporated on the model were designed to simulate only the center-of-gravity location, total mass, and rigid-body moment of inertia about the gimbal point of the full-scale engines. No provision was made for the engines to move with respect to the gimbal point, but actuator bending stiffness was simulated. Figure 6(b) shows a typical engine mount and simulated engine.

Measured values of model mass (with and without propellant) for each stage and for the complete model are given in table I. A photograph of the Saturn V model completely disassembled and with all major components identified is shown in figure 7. The first-stage propellants were simulated with solid metal (eutectic alloy); two lox-simulated and two fuel-simulated propellant tanks (nos. 15 and 14, respectively, in fig. 7), contained the metal. The amount of metal contained in the tanks could be varied so as to simulate the various flight times of the full-scale vehicle. Also included in the first stage were fuel and lox mechanical slosh simulators (no. 10 in fig. 7) whose design was based on a fuel-slosh mathematical analogy consisting of a spring-mass system which simulated the full-scale sloshing frequency. In the S-II and S-IVB stages of the model, the mass of the lox propellant was also simulated with eutectic alloy (see nos. 20 and 19, respectively, in fig. 7); however, the mass of the liquid hydrogen (LH_2) propellant was simulated with water (see nos. 13 and 16 in fig. 7). It should be noted that the volume of the propellants was not scaled, but their mass and relative center-of-gravity locations were simulated.

Launch umbilical tower (LUT).- The 1/40-scale model of the LUT consists of two principal structures, namely, (1) the umbilical tower and (2) the launch platform. The umbilical tower stands approximately 130 inches (330 cm) above the ground and 114 inches (289.6 cm) above the launch platform. The tower is approximately 12 inches (30.5 cm) square above its flared-out base. The rectangular platform measures 48.5 inches (123.2 cm) by 40.5 inches (102.9 cm) by 6.63 inches (16.84 cm). These dimensions were scaled from early architectural drawings of the full-scale structure.

The 1/40-scale model of the LUT is dynamically similar to the full-scale structure. The scaling laws established for the vehicle were used in the design of the LUT model; however, the LUT was constructed of steel and the modulus-of-elasticity ratio was therefore unity. Figure 8 shows the model of the launch platform during its construction phase; all joints were welded. Figure 9 shows the partially completed launch platform and a section of the tower. The tower is also an all-welded structure; however, it is bolted to the surface of the launch platform. The four vehicle holddown points and associated column structures, shown in figure 9, were scaled so as to represent the estimated longitudinal and lateral spring restraint.

The mass distribution, the center of gravity, and the rigid-body mass moments of inertia of the LUT structure were obtained by positioning steel ballast weights in the forms of cylinders and plates on the launch platform and tower, respectively, as shown in figures 10 and 11. These weights simulated the nonstructural mass of the platform and tower. The cylinders were bolted to the platform and the square plates were bolted to the tower structure at the four corners. When completely ballasted, the tower has a mass of 222 pounds (100.7 kg) and the platform has a mass of 382 pounds (173.2 kg). Both longitudinal and lateral spring restraints were simulated in the platform-to-ground support posts shown in figure 10.

Static-load-deflection curves for the tower are presented in figure 12. Tests were conducted with the force applied in two directions, normal to the perpendicular vertical sides of the tower. The results show that the tower deflected more when the load was applied in the plane of the widest base, or y-direction (see fig. 2); this fact indicates that the tower behaved as a truss-type structure, not as a beam.

TEST APPARATUS AND PROCEDURE

Shaker System and Test Configurations

One electromagnetic shaker having a force capability of 10 pounds (44.48 newtons) was used for all tests. The test results reported herein are presented for two directions of excitation, the x- and y-directions. The X-axis is defined as a horizontal line passing through the center lines of both the Saturn V model and the umbilical-tower model; the Y-axis is defined as a horizontal line perpendicular to the X-axis that bisects the longest side of the launch platform. Figures 10 and 11 show the shaker suspended by two cables and positioned so as to apply the force in the x- and y-directions, respectively.

A number of configurations were investigated. A summary of these configurations and the directions of excitation are presented in the following table:

Configuration	Shaker location	Direction of excitation
Saturn V model (cantilevered)	Saturn V model station 41.9 in. (106.4 cm)	x
Tower model (cantilevered)	Tower model station 67 in. (170.2 cm)	x and y
Tower model on launch platform	Launch platform	x and y
Saturn V-LUT model	Launch platform	x and y

Two mass conditions of the Saturn V model were investigated: (1) unfueled – with all stages empty but with the LM and the fueled service module included and (2) fueled – with the first stage of the model 85 percent full and all upper stages full.

Instrumentation, Testing, and Data Reduction

Vibration response, frequencies, and damping of the 1/40-scale Saturn V model were obtained from the output signal of lightweight, crystal accelerometers. The accelerometers were located on flanged joints where potential effects from local responses were minimized. (See fig. 3.) The LM and engine motions were also monitored with fixed accelerometers in the excitation plane.

The response of the 1/40-scale umbilical tower was measured by using heavier, servo-type accelerometers. These transducers were placed on the plate ballast weights located at the various levels along the tower height, as shown in figure 1. The launch platform was instrumented at the tower base, with an accelerometer on the platform surface and another on a cylindrical ballast weight located under the tower.

The testing procedure involved a frequency sweep at a rate of 0.145 octave per minute with a constant force input over a frequency range of 10 to 300 hertz for each configuration tested. The principal bending-mode frequencies were determined by monitoring the acceleration level measured at both the vehicle and tower tips. Each resonance was then tuned to its maximum response, where resonant frequencies, mode shapes, and damping of the structures were determined. The data were recorded on analog tape and were digitized by means of a 24-point-per-cycle conversion. The digitized data were then reduced by means of a harmonic analysis to determine the normalized mode shapes.

Damping data were obtained from the decay of oscillation recorded on an oscillograph when the force input was instantaneously terminated. Damping decrements were obtained for both the vehicle and the tower of the Saturn V-LUT configuration. The damping factor g was obtained from the relation

$$g = \frac{1}{n\pi} \log_e\left(\frac{x_o}{x_n}\right)$$

where x_o is the initial vibration amplitude, x_n is the vibration amplitude after n cycles, and n is the number of cycles.

RESULTS AND DISCUSSION

The primary objective of the test program was to determine the lateral vibration characteristics of a 1/40-scale dynamic model of the Saturn V-LUT configuration. The investigation was conducted on separated configurations and on an integral configuration. For the separated-configuration tests, the models of both the Saturn V vehicle and the tower were cantilevered. The integral configuration was studied with the vehicle and tower models mounted on the platform which was bolted to a rigid foundation – that is, with holddown boundary conditions simulated. The results are presented for two directions of excitation and for two simulated mass conditions of the vehicle. A summary of the frequencies and damping is presented in tables II to V and the frequency responses and mode shapes are shown in figures 13 to 29. In these figures the Saturn V model length is normalized to the tip longitudinal station 107 inches (272 cm). It should be noted that the mode shapes of the vehicle are normalized to the deflection at station 104 inches (264 cm) and not to the deflection at the tip station.

Cantilevered 1/40-Scale Saturn V Model

A summary of the cantilever resonant frequencies and associated damping of the 1/40-scale model of Saturn V obtained for two simulated mass conditions is presented in table II. Tests were conducted in only one direction since the model was assumed symmetric. The results are presented for the unfueled and fueled conditions and the corresponding mode shapes are presented in figures 13 and 14, respectively. Four cantilever modes are presented for the unfueled condition and five cantilever modes are presented for the fueled condition. The identity for the cantilevered modes was based on the characteristic mode shapes of a cantilever beam.

Cantilevered 1/40-Scale Umbilical Tower

Measured cantilever resonant frequencies and associated damping of the 1/40-scale tower mounted on a rigid foundation are summarized in table III. The data are presented for the x- and y-directions, and the corresponding mode shapes are shown in figures 15 and 16, respectively. With the exception of the first mode in the x-direction, the mode shapes of the tower exhibit rotation at the tower base rather than a 0° slope characteristic of a cantilever beam. This behavior was verified with a movable-accelerometer survey and can probably be explained by the fact that the tower is essentially a truss structure and that, in such structures, bending stresses in individual members are usually small compared with stresses due to axial forces (ref. 6). Thus, the joints of the tower behaved as if they were pinned, and classical analyses have shown that such an assumption is realistic for truss structures.

The first cantilever mode of the tower was unique in that it responded out of the plane of the exciting force. The two mode shapes presented as the first mode in the x- and y-directions, figures 15(a) and 16(a), respectively, represent components of the out-of-plane resonances measured in these directions; no out-of-plane deflection was observed in the static test (see fig. 12). Figure 17 shows how the frequency response of the fundamental mode as measured at the tower tip varied with the plane of excitation;

the shaker force remained constant and the response was measured in the plane of excitation. The frequency and response differentials shown in figures 17(b) and 17(c) indicate that the tower is not dynamically symmetric about its axes of symmetry; rather the principal response axes of the tower are oriented approximately 45° from these axes. This anomaly may be attributed to asymmetries of construction. In addition, the fundamental mode in the y-direction (see fig. 16(a)) shows a negative rotation about the base. A manual survey of the tower response indicated that the tower appeared to pivot just above the flared-out area which tended to impart similar rotational motion below this point. All the remaining modes obtained were planar modes – that is, the tower did not respond out of the excitation plane.

Model of Tower on Launch Platform Without Saturn V

The modes reported hereinafter are identified by numbers corresponding to the consecutive number of resonant peaks as they appeared on the frequency sweeps for each configuration tested, and no attempt was made to relate the modal identity to characteristic shapes as was done for the previously discussed results from the tests of the models having cantilevered-end conditions. The frequency responses of the tower on the launch platform are normalized to the maximum response, since the intent is to show the relative shapes of the response curves and the distribution of peaks.

Results for the tower mounted on the launch platform are given for force applied in the x- and y-directions. For this and all the remaining test configurations involving the launch platform, a constant excitation force was applied at the launch platform. The frequency response measured at the tower tip when the force is being applied in the x-direction and the associated mode shapes are shown in figures 18 and 19, respectively; similarly, the results obtained in the y-direction are shown in figures 20 and 21. In addition, the frequency responses measured during the cantilevered-tower tests (normalized to the maximum cantilever response) are superimposed in figures 18 and 20. A comparison shows that when the tower is mounted on the launch platform instead of on a rigid foundation, the resonant frequencies of the tower tended to decrease but the number of resonant peaks increased. The decrease of resonant frequencies is caused by the effective spring of the platform-to-ground support posts. This effect is represented by the launch-platform displacement in figure 19(b) and by a reduction of 12.5 percent in the second resonant frequency when the tower is mounted on the launch platform instead of on a rigid foundation. Furthermore, an investigation of the platform motion indicated that the base did not respond out of the plane of excitation; similar platform-motion results were observed for the model of the complete Saturn V-LUT configuration. The launch platform was ballasted with solid steel cylinders of various sizes (see figs. 10 and 11); each was connected to the platform by means of a single bolt. The ballast weights responded strongly as cantilevered beams in the higher frequency range (above

90 hertz) and coupled with the launch platform and tower to produce some of the new resonances which were obtained for this particular configuration.

Some of the tower resonances during the cantilever condition appear to be attenuated on the frequency response curves (for example, see the fourth cantilevered-tower response in figure 18 and the third and fourth cantilevered-tower responses in fig. 20). This result was due to the fact that the tower was excited at station 67 inches (170.2 cm) which is near a nodal point of these modes.

Model of Integral Saturn V-LUT Configuration

The remaining results cover the tests performed on the model of the complete Saturn V-LUT configuration with simulated holddown conditions. These data were obtained with approximately 3.94 pounds (17.5 newtons) of excitation force applied to the launch platform at locations shown in figures 10 and 11. The frequency responses (measured at the vehicle and tower tips) shown for this configuration are normalized to the maximum response of the Saturn V model tip. Table IV summarizes the resonant frequencies of the Saturn V and tower models with the shaker applying force in the x-direction; the associated frequency response curves and mode shapes are shown in figures 22 and 23 and figures 24 and 25 for model unfueled and fueled mass conditions, respectively. Resonant frequencies and damping values obtained in the y-direction are summarized in table V, and the corresponding frequency response curves and mode shapes are presented in figures 26 and 27 and figures 28 and 29 for model unfueled and fueled conditions, respectively.

The results indicate considerable interaction between the vehicle and launch umbilical tower. However, little coupling was observed below 60 hertz (1.5 hertz, full-scale equivalent), even though the first cantilever modes of the vehicle and tower occur below this frequency. In fact, the first cantilever mode of the vehicle could not be excited in either the unfueled or fueled condition without reorientation of the shaker to apply the force at the second-stage model thrust structure, station 41.9 inches (106.4 cm). The results are shown in figures 23(a) and 25(a). Figure 25(b) shows a mechanical-slosh mode shape measured at 12.9 hertz; this mode of response results from the use of a particular spring-mass system to simulate sloshing. These modes were obtained in the x-direction; however, because of the symmetry of the vehicle, it is assumed that they would have also appeared in the y-direction if the force had been applied to the vehicle in the y-direction.

In tables IV and V, values of the damping factor g measured at the vehicle and tower are given for many of the modes of the configuration. Low values of damping were observed, particularly for the first tower mode where values on 0.0017 and 0.0013 were obtained with the shaker applying force in the x- and y-directions, respectively.

It was observed that the tower response generally exhibited a greater coupling influence than did the Saturn V response at the higher frequencies. The frequency response curves in figures 22, 24, 26, and 28 show that at nearly all the resonances where the tower responded, the Saturn V also responded, but that, conversely, the Saturn V responded in many resonances where the tower did not respond. No coupled response between the Saturn V model and tower model was observed below 60 hertz.

Many of the mode shapes show that the escape tower of the Saturn V model experienced relatively large deflections. Thus, the vehicle response appears greater than that of the umbilical tower.

CONCLUDING REMARKS

An experimental investigation has been conducted to determine the bending vibration characteristics of the Saturn V-LUT configuration with the use of 1/40-scale dynamic models. The results and description of the models of the Saturn V vehicle and its launch umbilical tower are presented. The results consist of resonant frequencies, mode shapes, and damping values of the Saturn V model and its umbilical tower, considered separately and as an integral configuration mounted on the launch platform. The results are given for two directions of excitation and for fueled and unfueled conditions of the vehicle over a frequency range of 10 to 300 hertz (0.25 to 7.5 hertz, full-scale equivalent).

The response of the tower in its first mode was out of the excitation plane; the principal response axes were oriented diagonally across the square cross section of the tower. All the remaining resonances of the tower occurred in the planes of geometric symmetry. The results for the 1/40-scale Saturn V-LUT configuration indicate strong coupled response between the vehicle and the tower at the higher frequencies but little coupling at the lower frequencies (below 60 hertz or 1.5 hertz, full-scale equivalent).

Langley Research Center,
National Aeronautics and Space Administration,
Langley Station, Hampton, Va., May 21, 1968,
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TABLE I.- SUMMARY OF PHYSICAL CHARACTERISTICS FOR 1/40-SCALE MODEL OF SATURN V

Component	Length		Mass without propellant		Mass with propellant		Center-of-gravity longitudinal station (without propellant)	
	in.	cm	lb	kg	lb	kg	in.	cm
First stage S-IC (includes engines)	41.4	105.2	16.56	7.51	239.81	108.78	11.83	30.05
Second stage S-II (includes engines and S-IC/S-II interstage)	24.4	62.0	5.30	2.40	64.30	29.16	47.38	120.34
Third stage S-IVB (includes engine, aft skirt, and S-II/S-IVB interstage)	18.4	46.7	2.00	.91	16.12	7.31	70.02	177.85
LM adapter (includes LM)	9.4	23.9	2.00	.91	2.00	.91	83.83	212.93
Command and service modules and launch escape system	16.2	41.1	4.31	1.96	4.31	1.96	93.55	237.62
Total model	109.8	278.9	30.17	13.69	326.54	148.12	----	-----

TABLE II.- SUMMARY OF CANTILEVER RESONANT FREQUENCIES AND ASSOCIATED DAMPING FOR 1/40-SCALE SATURN V MODEL

Cantilever mode	Unfueled condition		Fueled condition	
	Frequency, Hz	Damping factor g	Frequency, Hz	Damping factor g
1st	18.0	0.007	10.9	0.0163
2nd	71.8	.0094	34.7	.0086
3rd	118.6	.010	63.2	-----
4th	188.9	.0139	95.7	.0082
5th	----	-----	127.0	-----

TABLE III.- SUMMARY OF CANTILEVER RESONANT FREQUENCIES AND ASSOCIATED DAMPING FOR 1/40-SCALE TOWER

Cantilever mode	x-direction		y-direction	
	Frequency, Hz	Damping factor g	Frequency, Hz	Damping factor g
1st	28.2	-----	28.2	0.0069
	29.8	0.0035	29.8	-----
2nd	77.1	.0040	95.0	.0066
3rd	139.1	.0021	173.8	-----
4th	214.0	-----	227.1	-----
5th	269.0	-----	273.3	-----

TABLE IV.- SUMMARY OF RESONANT FREQUENCIES AND DAMPING FOR SATURN V-LUT MODEL WITH SHAKER APPLYING FORCE AT LAUNCH PLATFORM IN x-DIRECTION

Mode number	Unfueled condition			Fueled condition		
	Frequency, Hz	Damping factor g	Predominant response	Frequency, Hz	Damping factor g	Predominant response
1	17.3	0.0083	Saturn V	9.5	0.0137	Saturn V
2	27.3	.0017	Tower	12.9	.008	Saturn V
3	66.1	[a].0046; [b].0091 to .003	Coupled	28.4	.0017	Tower
4	70.7	-------------------	Saturn V	34.9	.0058	Saturn V
5	109.3	[b].0087 to .0058	Coupled	61.9	[a].0073	Coupled
6	115.5	-------------------	Coupled	68.1	a and [b].0033	Coupled
7	140.1	[b].012 to .003	Coupled	98.1	[a].0088	Coupled
8	[c]167.0	-------------------	Saturn V	111.9	a and [b].0055	Coupled
9	189.8	-------------------	Saturn V	127.7	-----------	Saturn V
10	213.7	[b].0147	Coupled	140.5	[b].0052	Coupled
11	[c]267.5	-------------------	Coupled	215.1	-----------	Tower

[a]Damping value for Saturn V model.

[b]Damping value for tower model (when two values are given for tower model, the first value is that obtained for a large decaying amplitude and the second is that obtained for a small decaying amplitude).

[c]Frequency value taken from sweep data (no corresponding mode shapes are given in the report).

TABLE V.- SUMMARY OF RESONANT FREQUENCIES AND DAMPING FOR SATURN V-LUT MODEL WITH SHAKER APPLYING FORCE AT LAUNCH PLATFORM IN y-DIRECTION

Mode number	Unfueled condition			Fueled condition		
	Frequency, Hz	Damping factor g	Predominant response	Frequency, Hz	Damping factor g	Predominant response
1	28.2	0.0013	Tower	28.4	0.0013	Tower
2	72.1	.0092	Saturn V	35.0	-----------	Saturn V
3	85.3	[b].0087	Coupled	62.9	.0065	Saturn V
4	113.3	------------	Coupled	85.8	a and [b].0037	Coupled
5	124.0	[a].0047; [b].0058	Coupled	97.1	[a].0045	Coupled
6	[c]163.0	------------	Coupled	122.3	-----------	Coupled
7	175.1	a and [b].0011	Coupled	128.0	-----------	Coupled
8	[c]186.0	------------	Saturn V	[c]146.0	-----------	Saturn V
9	[c]189.0	------------	Saturn V	[c]182.0	-----------	Tower
10	[c]210.0	------------	Tower	[c]210.0	-----------	Tower
11	[c]264.0	------------	Tower	[c]254.0	-----------	Tower
12				[c]263.5	-----------	Tower

[a]Damping value for Saturn V model.

[b]Damping value for tower model.

[c]Frequency value taken from sweep data (no corresponding mode shapes are given in the report).

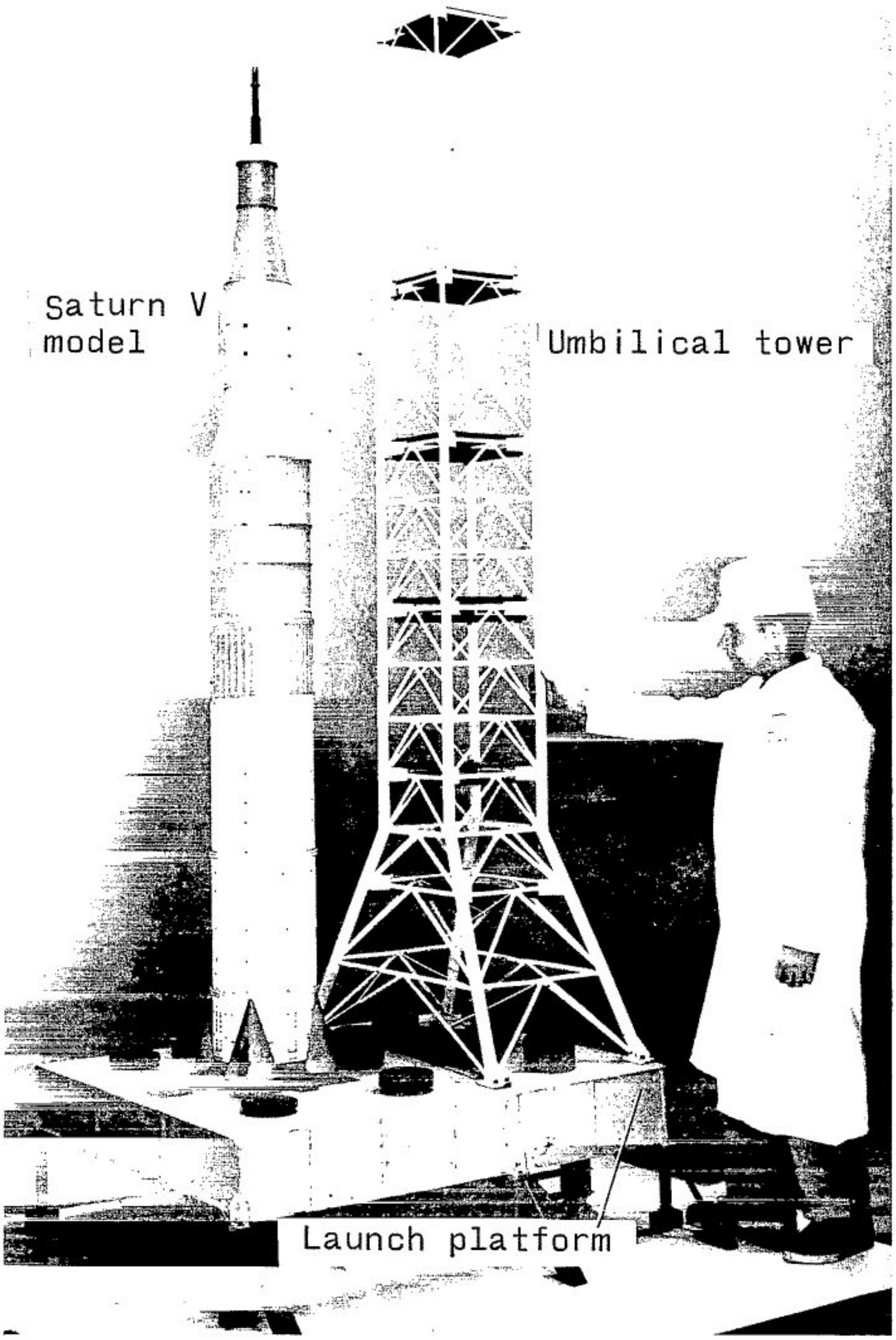


Figure 1.- A 1/40-scale dynamic model of Saturn V-LUT configuration with simulated holddown conditions. L-64-8910.1

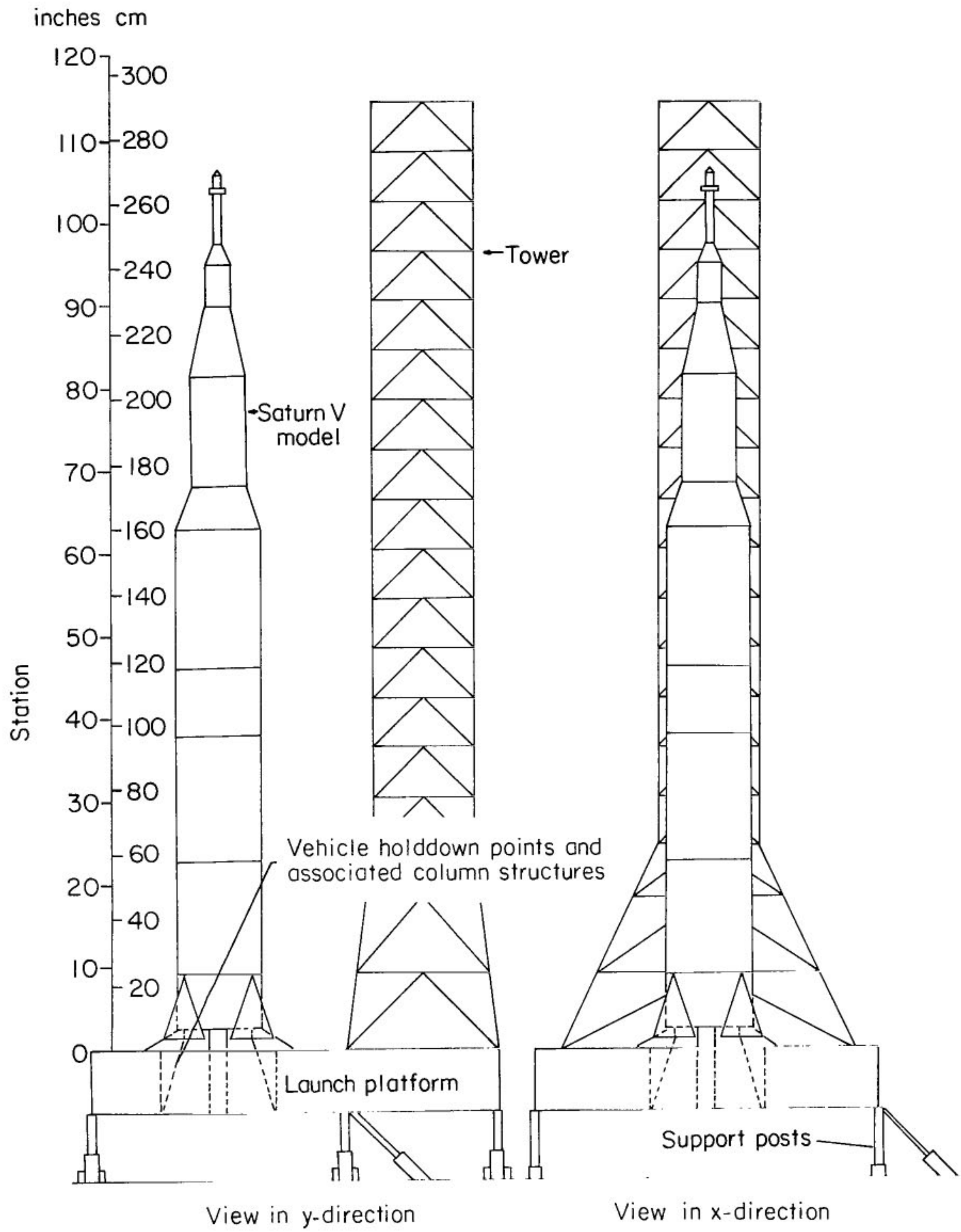


Figure 2.- General nomenclature and dimensions of 1/40-scale Saturn V-LUT configuration.

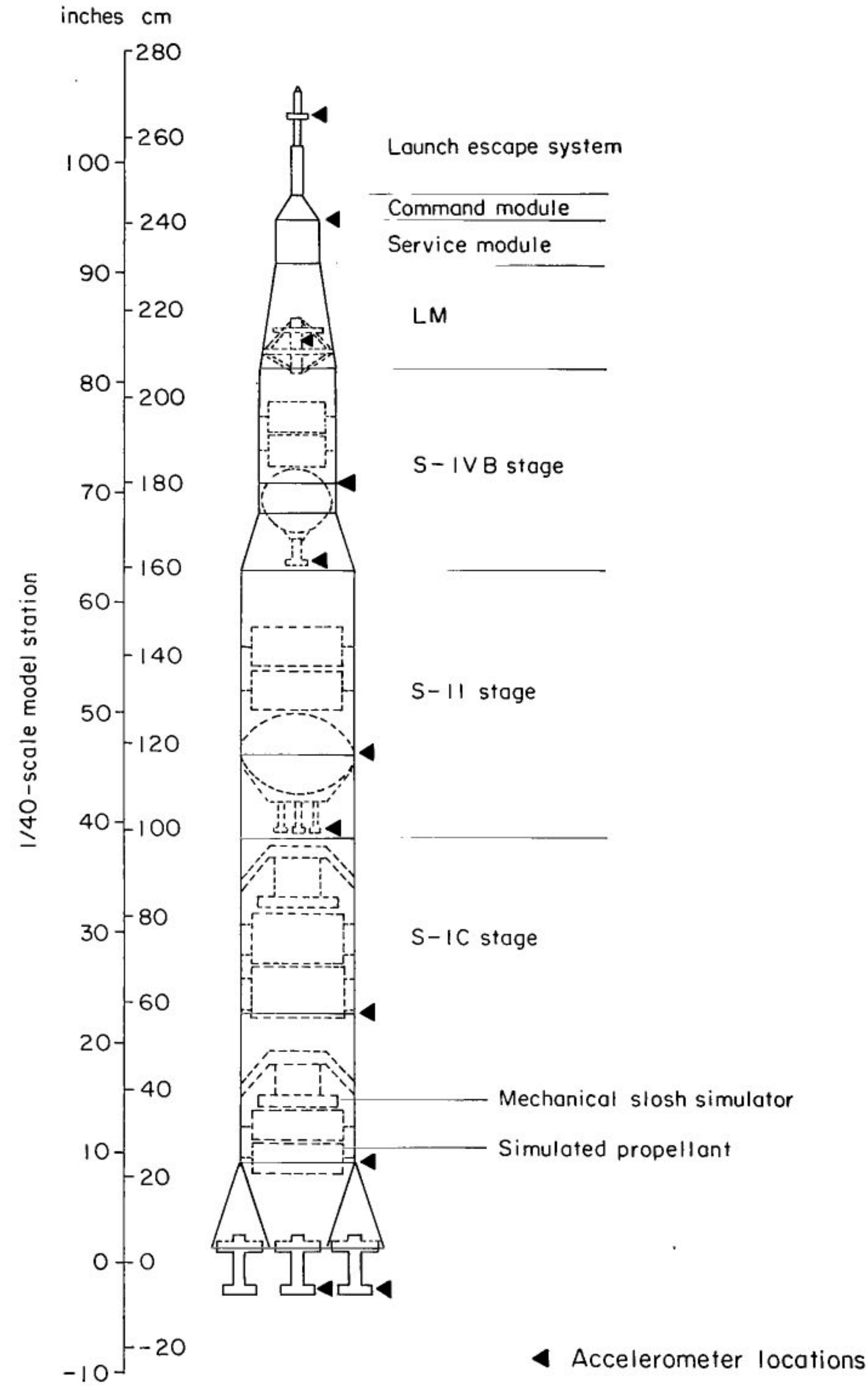


Figure 3.- Sketch of 1/40-scale Saturn V model.

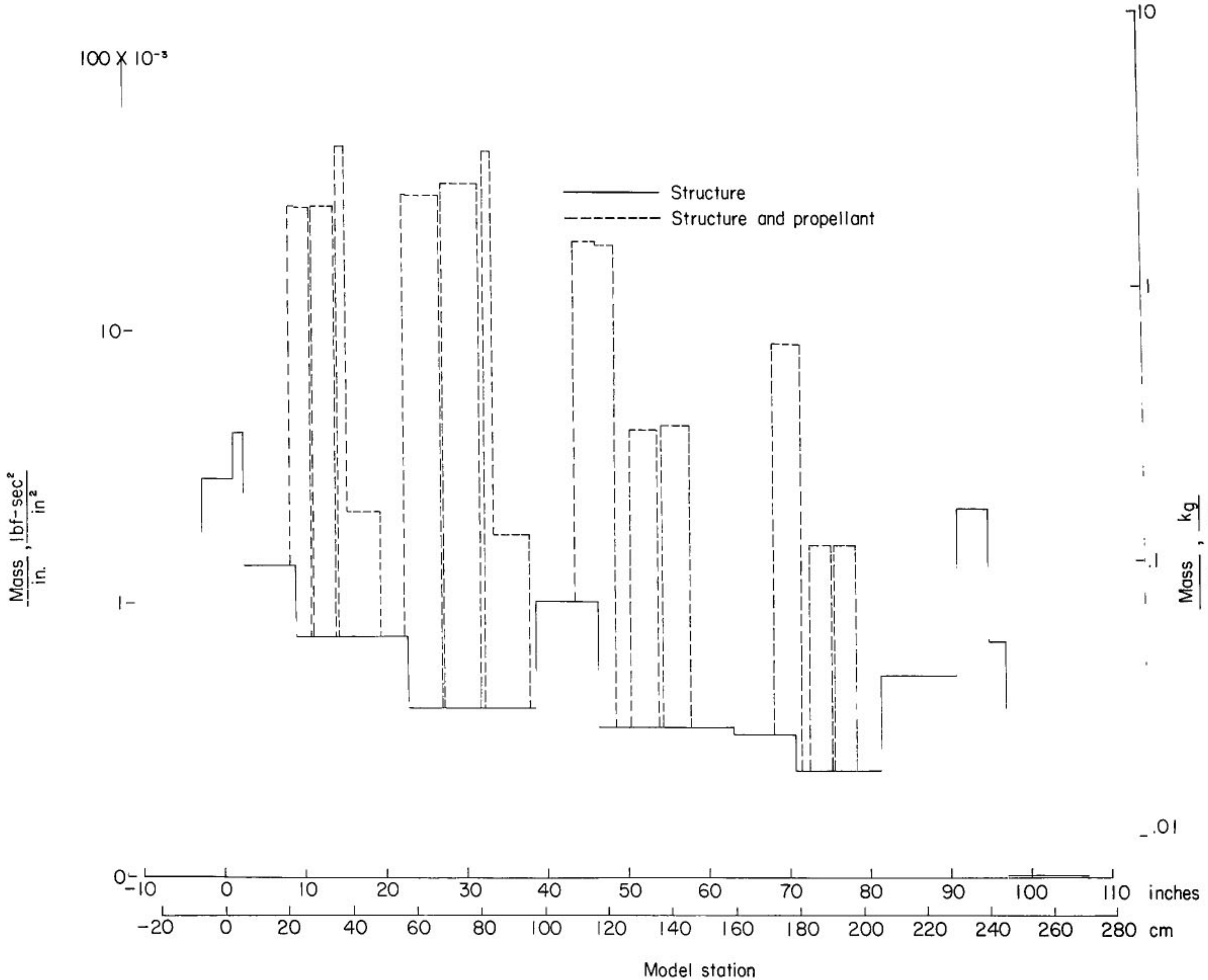


Figure 4.- Mass distribution of 1/40-scale model of Saturn V.

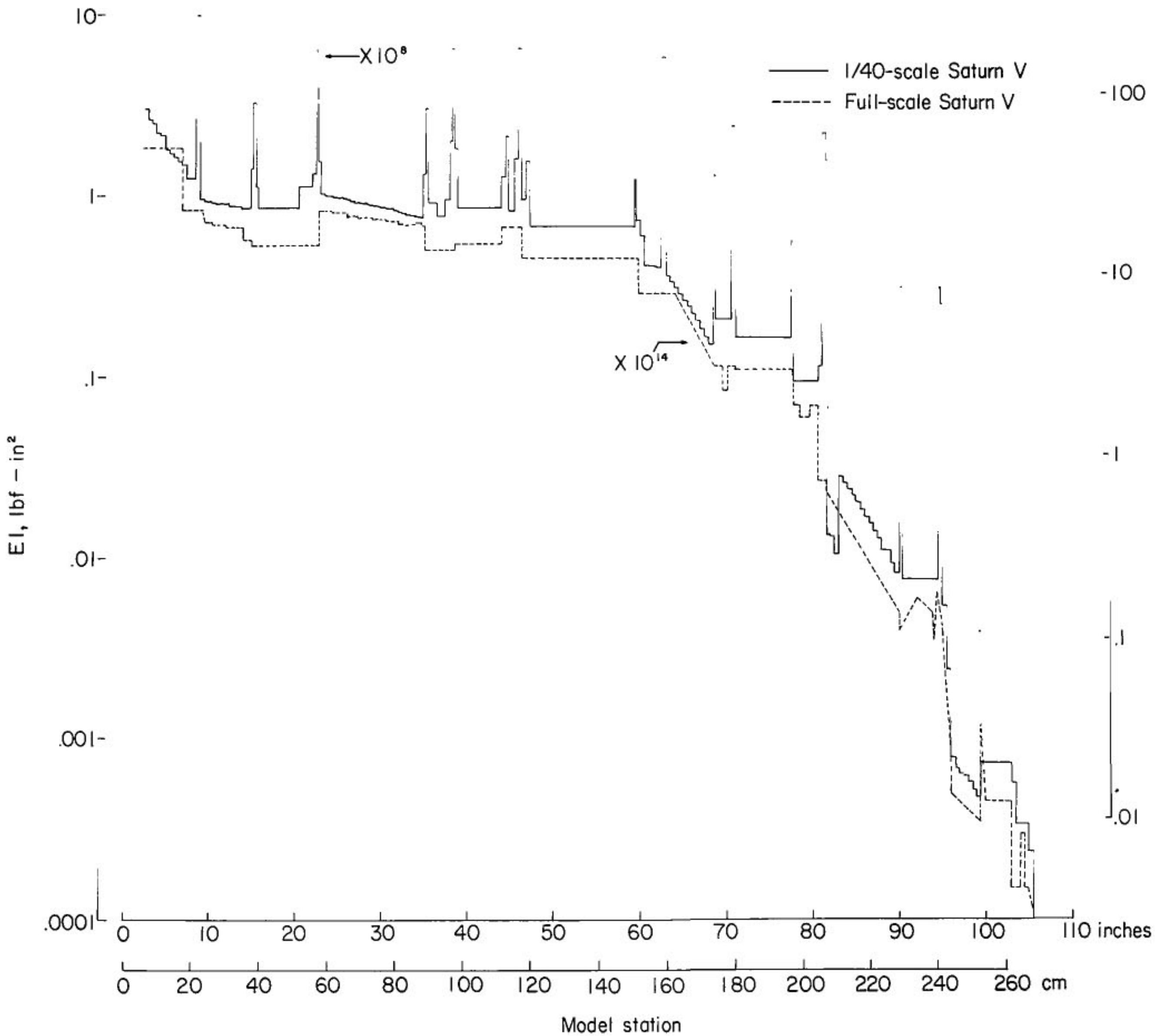
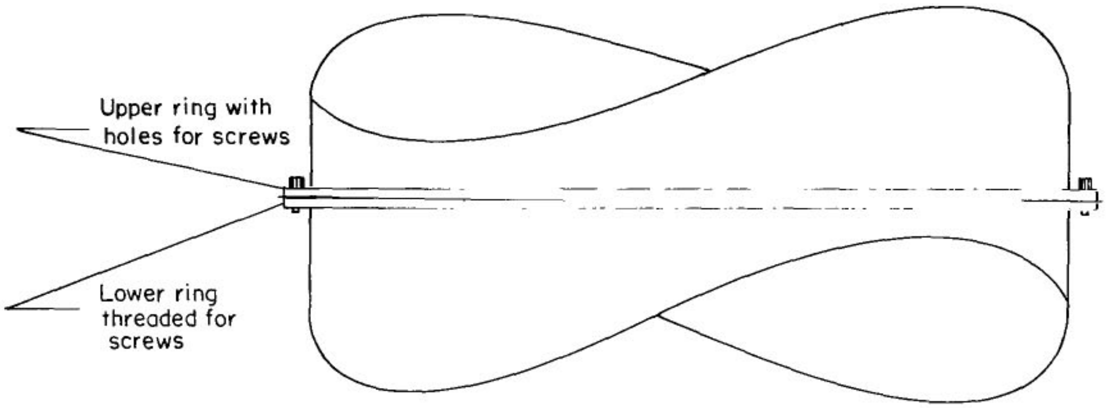
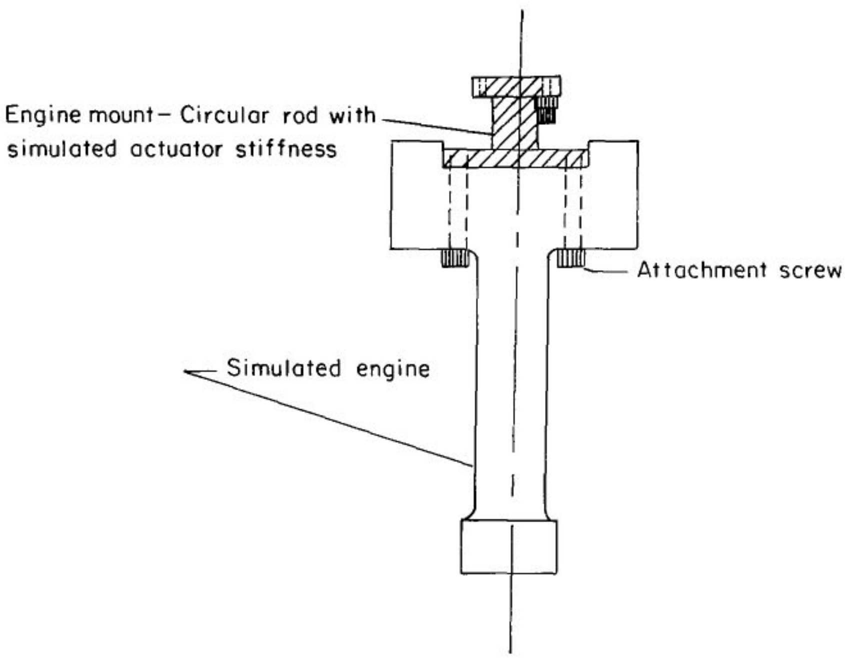


Figure 5.- Bending stiffness distribution of 1/40-scale and full-scale Saturn V.



(a) Details of a typical flanged joint.



(b) Typical engine simulation.

Figure 6.- Typical assembly details of 1/40-scale Saturn V model.

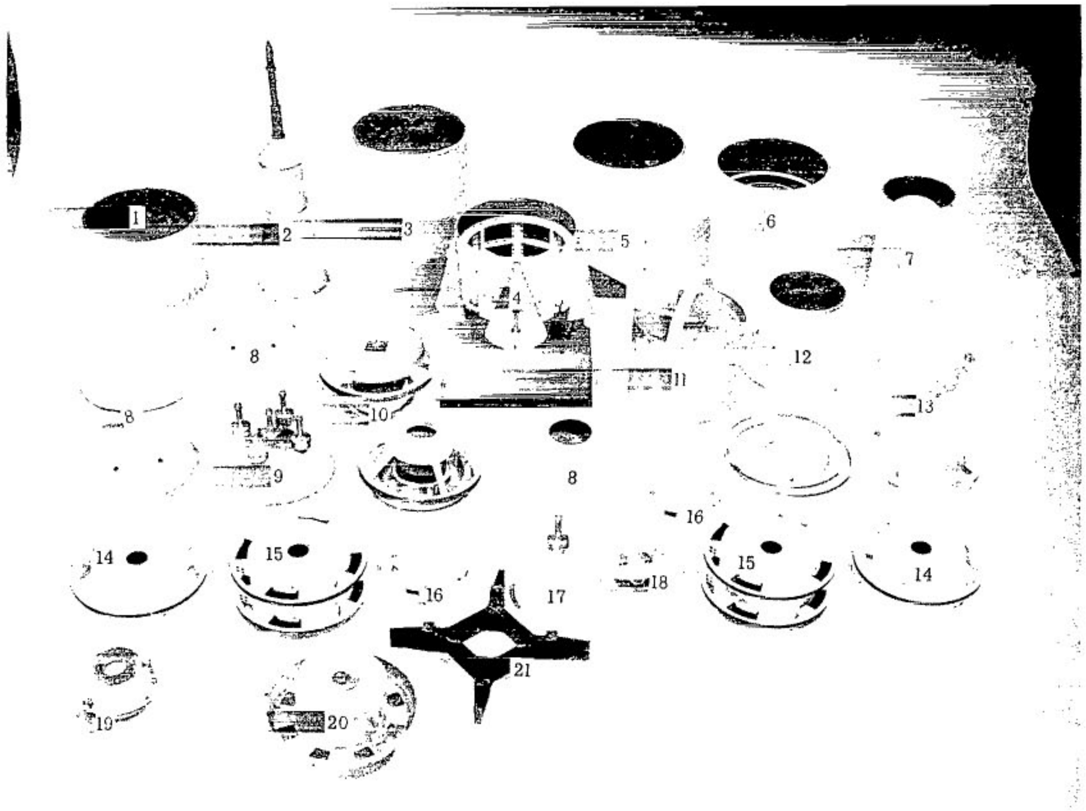


Figure 7.- Components of 1/40-scale model of Saturn V. L-68-897

1	S-IC/S-II interstage
2	Launch escape system, command and service modules, and LM adapter
3	S-II stage, LH_2 tank, and forward skirt
4	S-IC thrust structure with cantilever test stand (simulated F-1 engine not shown)
5	S-IC stage, lox tank, and forward skirt
6	S-IC stage, fuel tank, and intertank
7	S-IVB stage, LH_2 bulkhead, LH_2 tank, and forward skirt
8	Nonstructural bulkheads
9	S-II simulated J-2 engines and thrust cone
10	S-IC mechanical slosh simulators for lox and fuel (one in background is inverted)
11	Longitudinal simulated propellant (not used for these tests)
12	S-IVB stage, S-II/S-IVB interstage, and aft skirt
13	S-II LH_2-simulated-propellant tanks
14	S-IC fuel-simulated-propellant tanks
15	S-IC lox-simulated-propellant tanks
16	S-IVB LH_2-simulated-propellant tanks
17	S-IVB simulated J-2 engine, thrust structure, and lox lower bulkhead
18	Simulated LM
19	S-IVB lox-simulated-propellant tank
20	S-II lox-simulated-propellant tank with heater
21	Suspension cradle (not used for these tests)

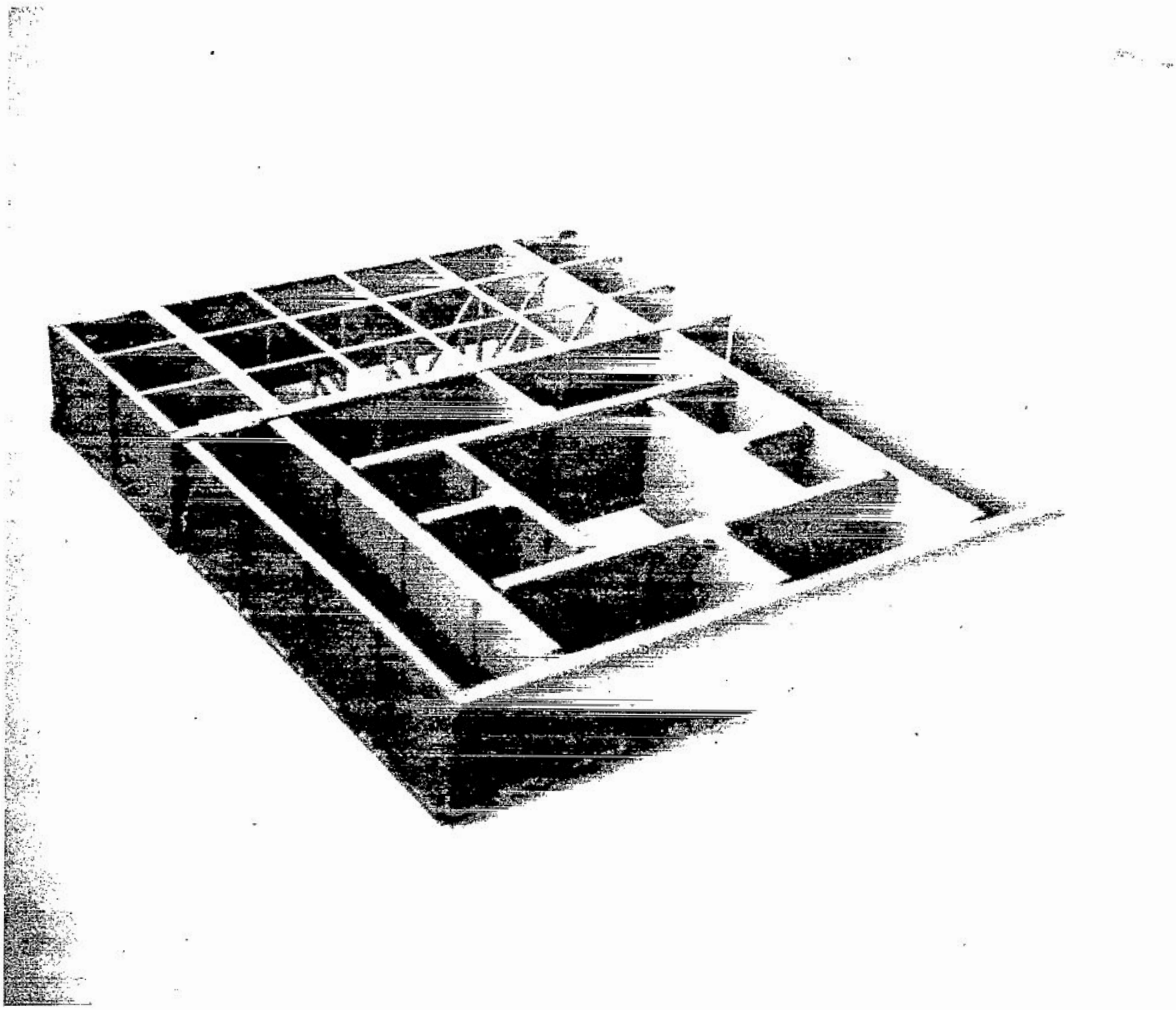


Figure 8.- Subassembly of 1/40-scale launch platform. L-68-898

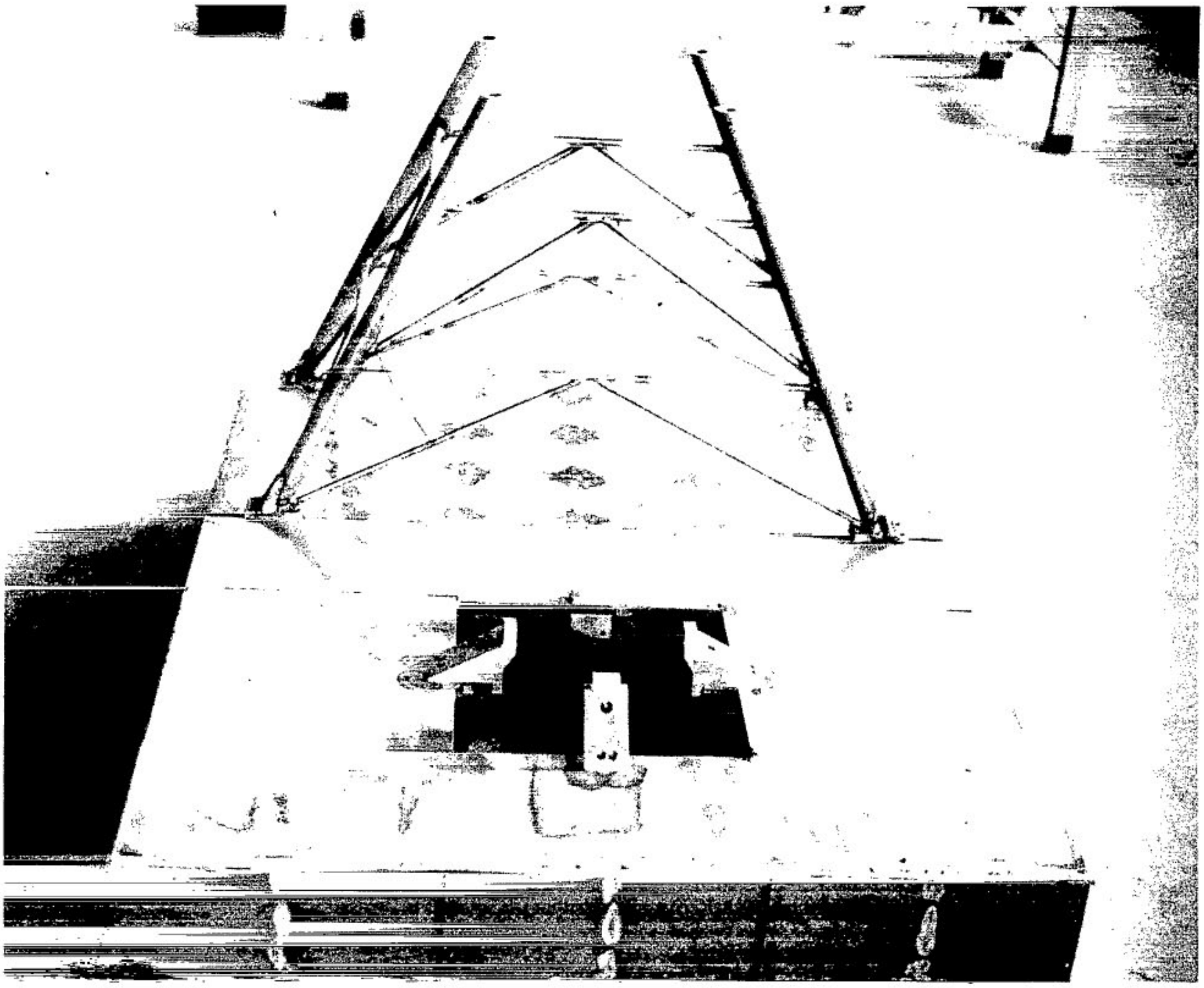


Figure 9.- 1/40-scale launch platform with portion of umbilical tower bolted to surface. L-68-899

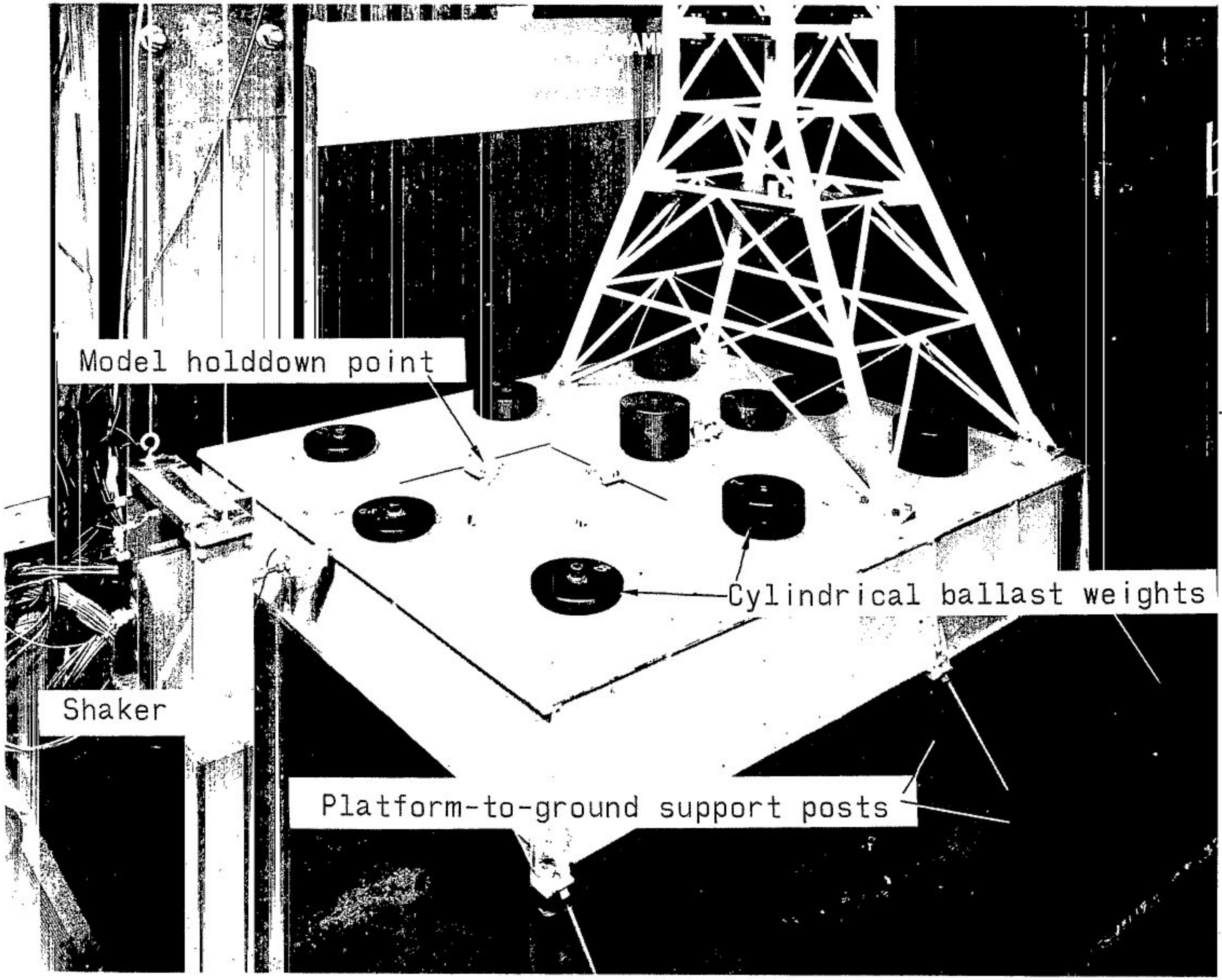


Figure 10.- 1/40-scale dynamic model of the LUT with shaker oriented to apply the force in x-direction. L-65-7297.1

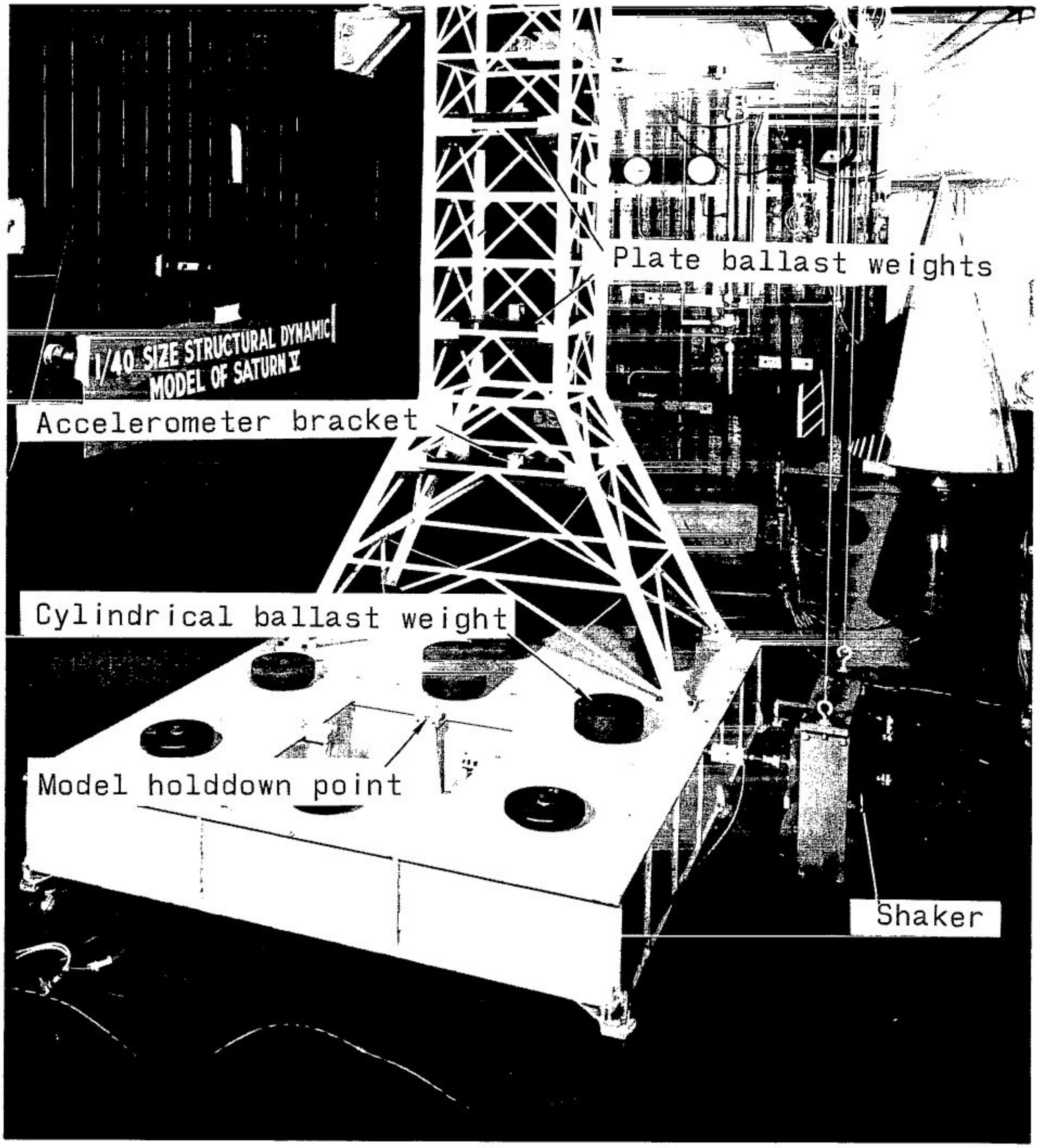


Figure 11.- 1/40-scale dynamic model of the LUT with shaker oriented to apply the force in y-direction. L-65-7298.1

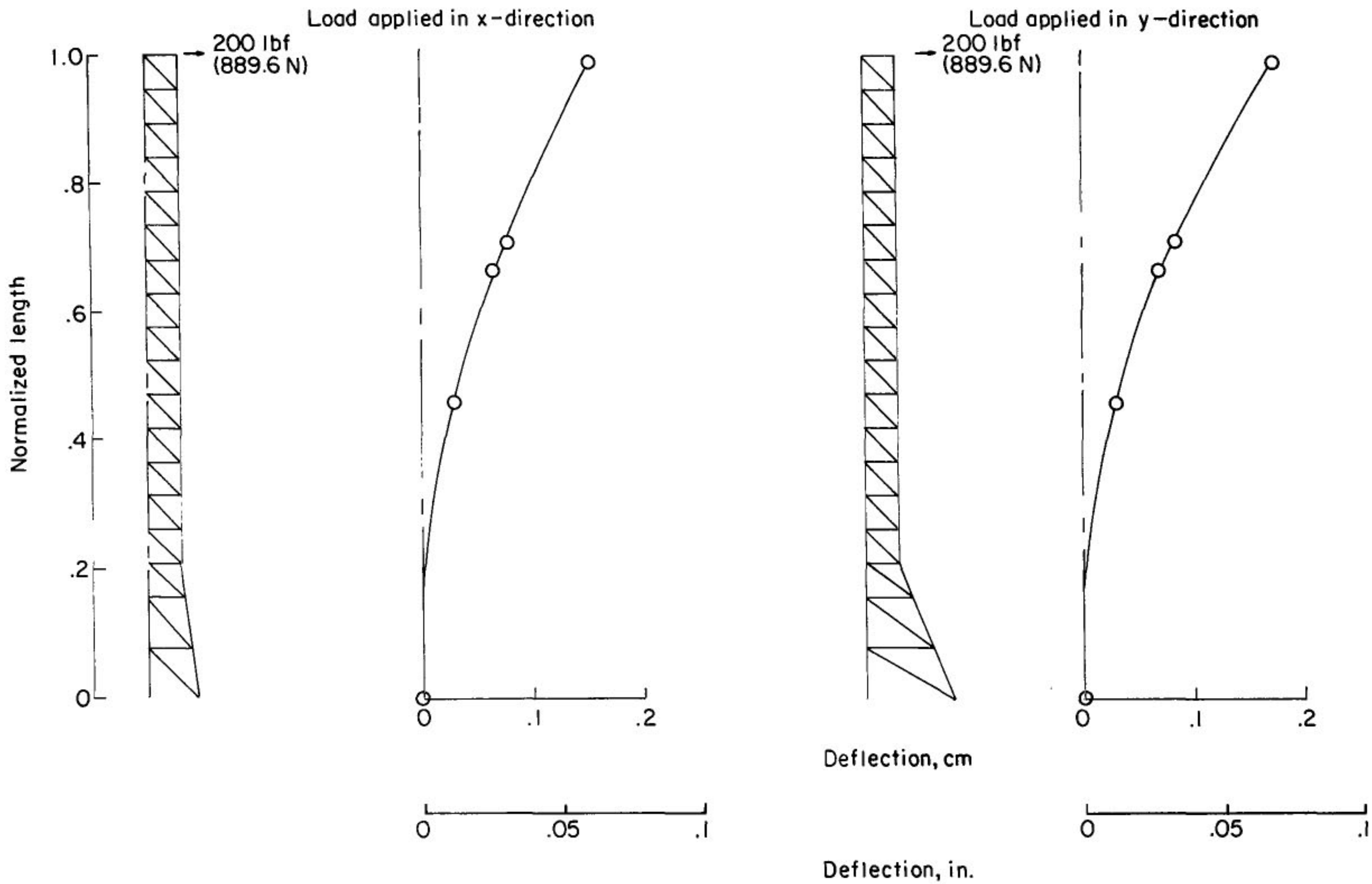
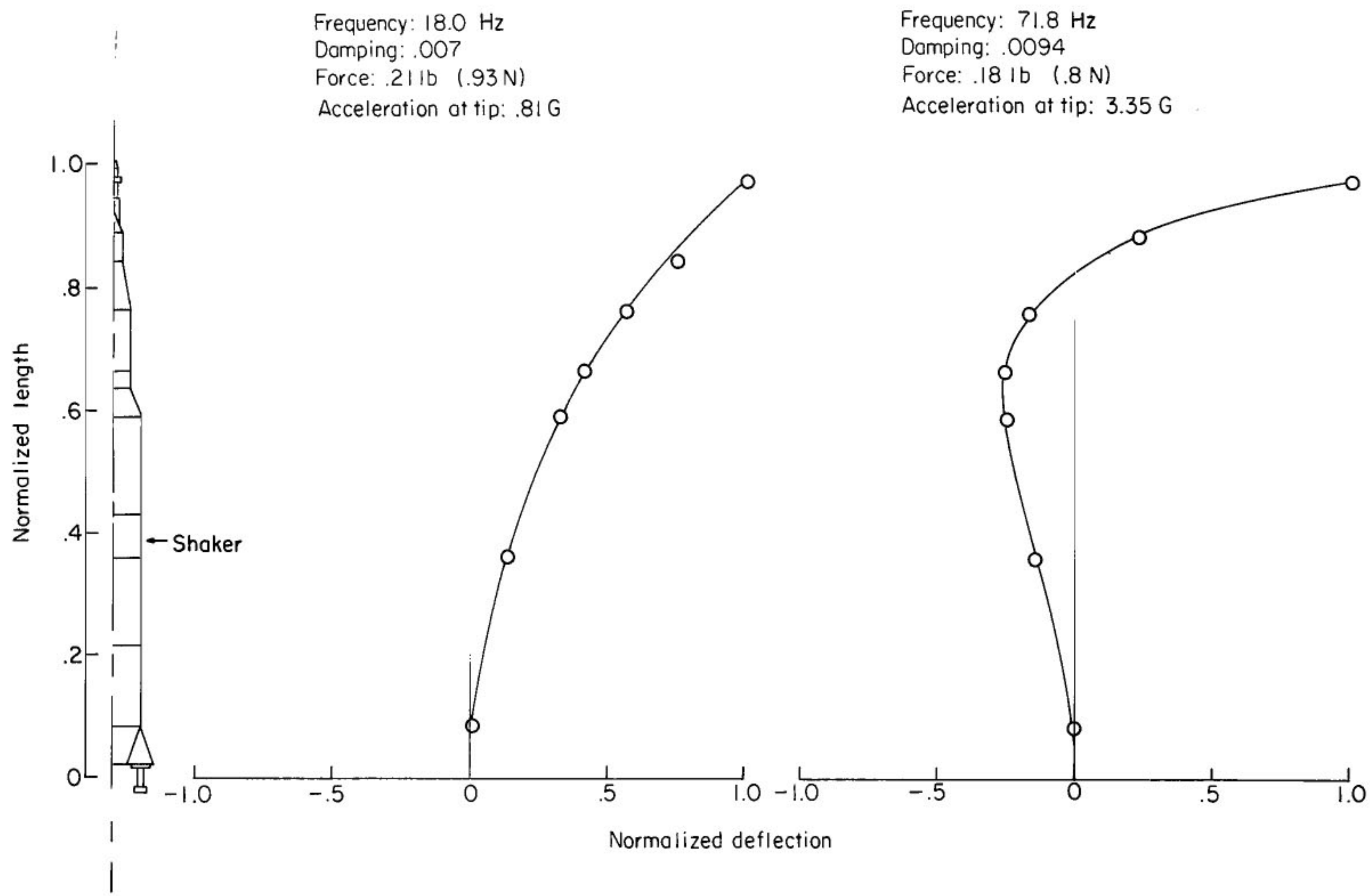


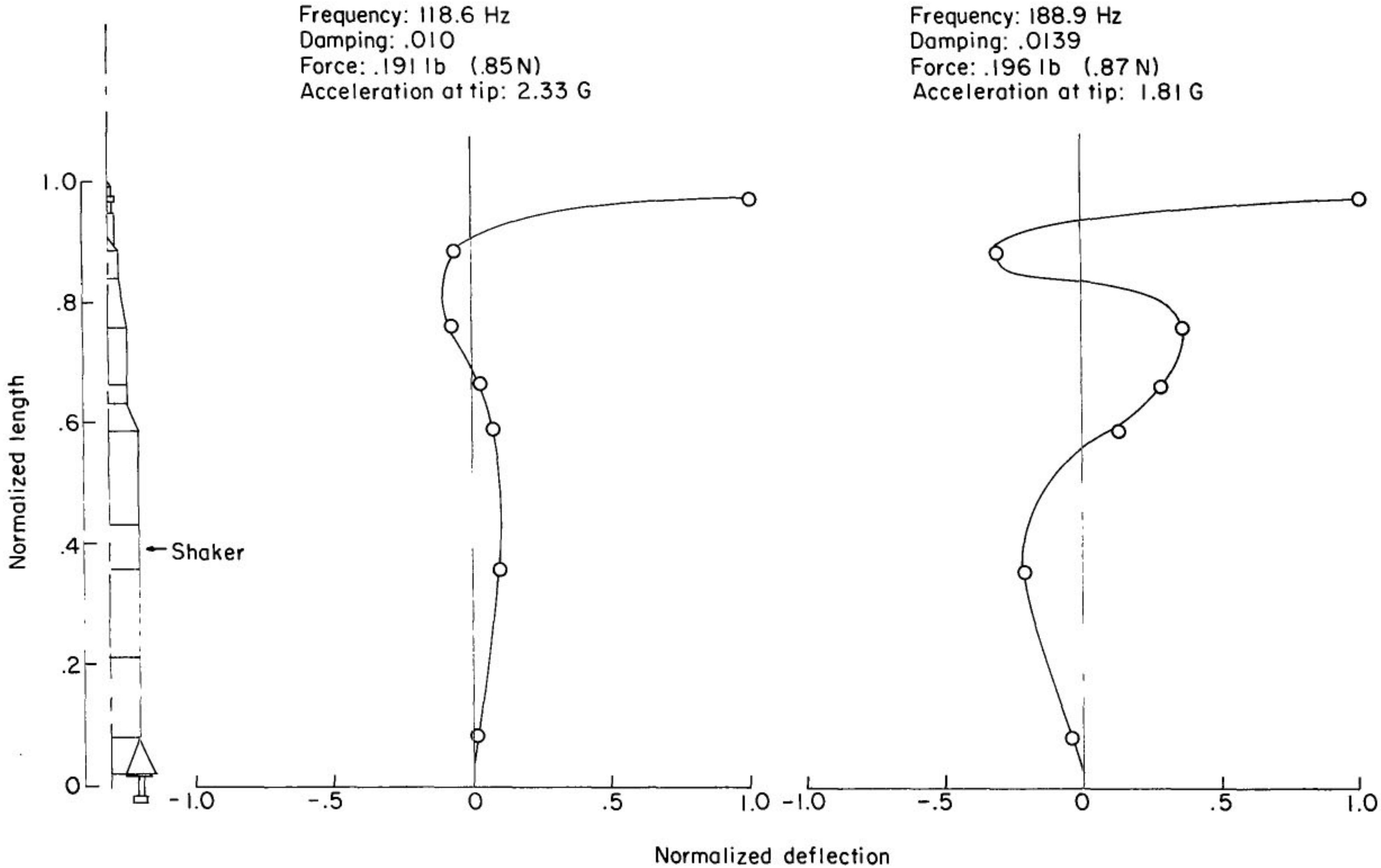
Figure 12.- Static-load-deflection test results for tower model.



(a) First mode

(b) Second mode.

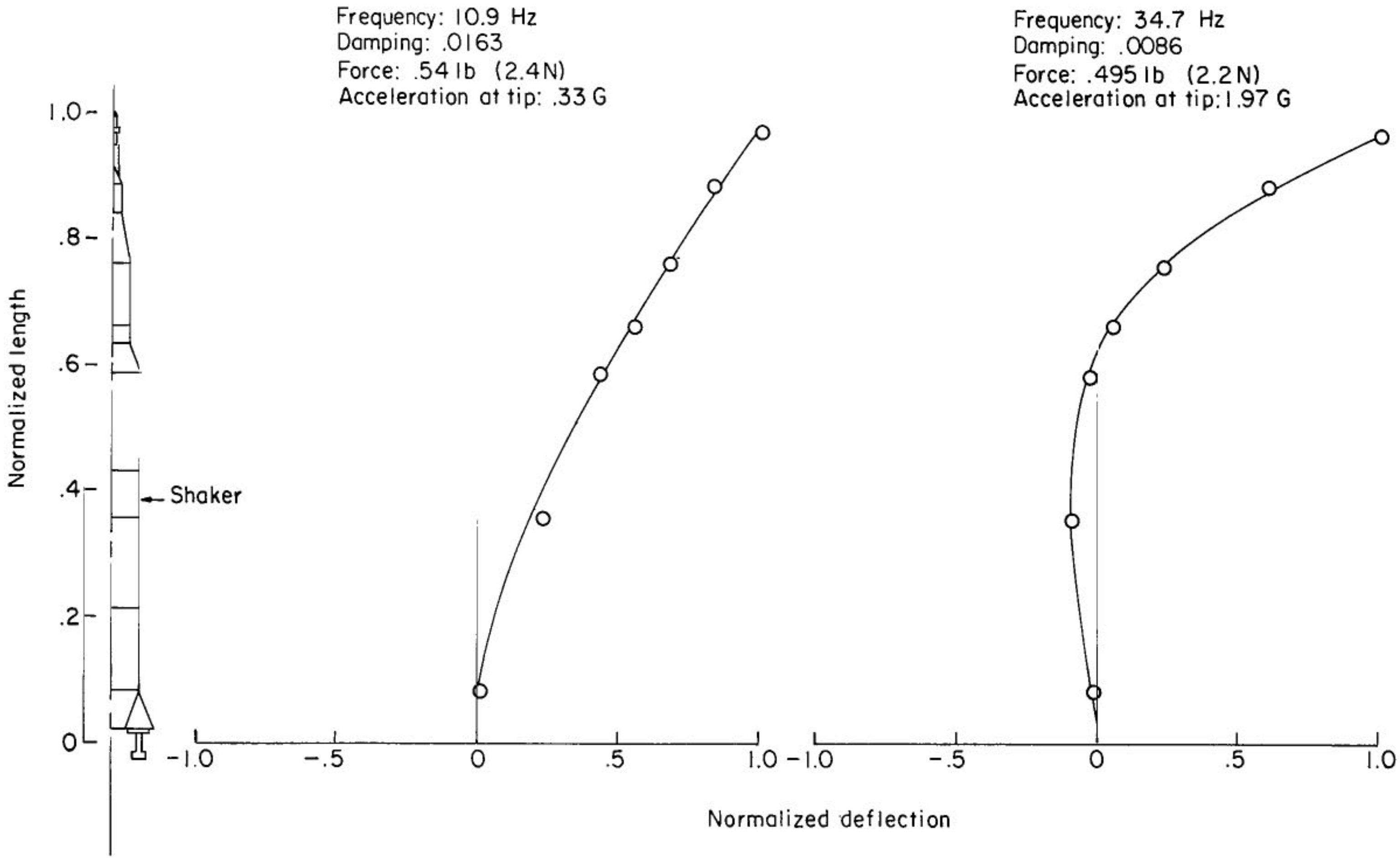
Figure 13.- Normalized cantilever mode shapes of the 1/40-scale Saturn V model in the unfueled condition.



(c) Third mode.

(d) Fourth mode.

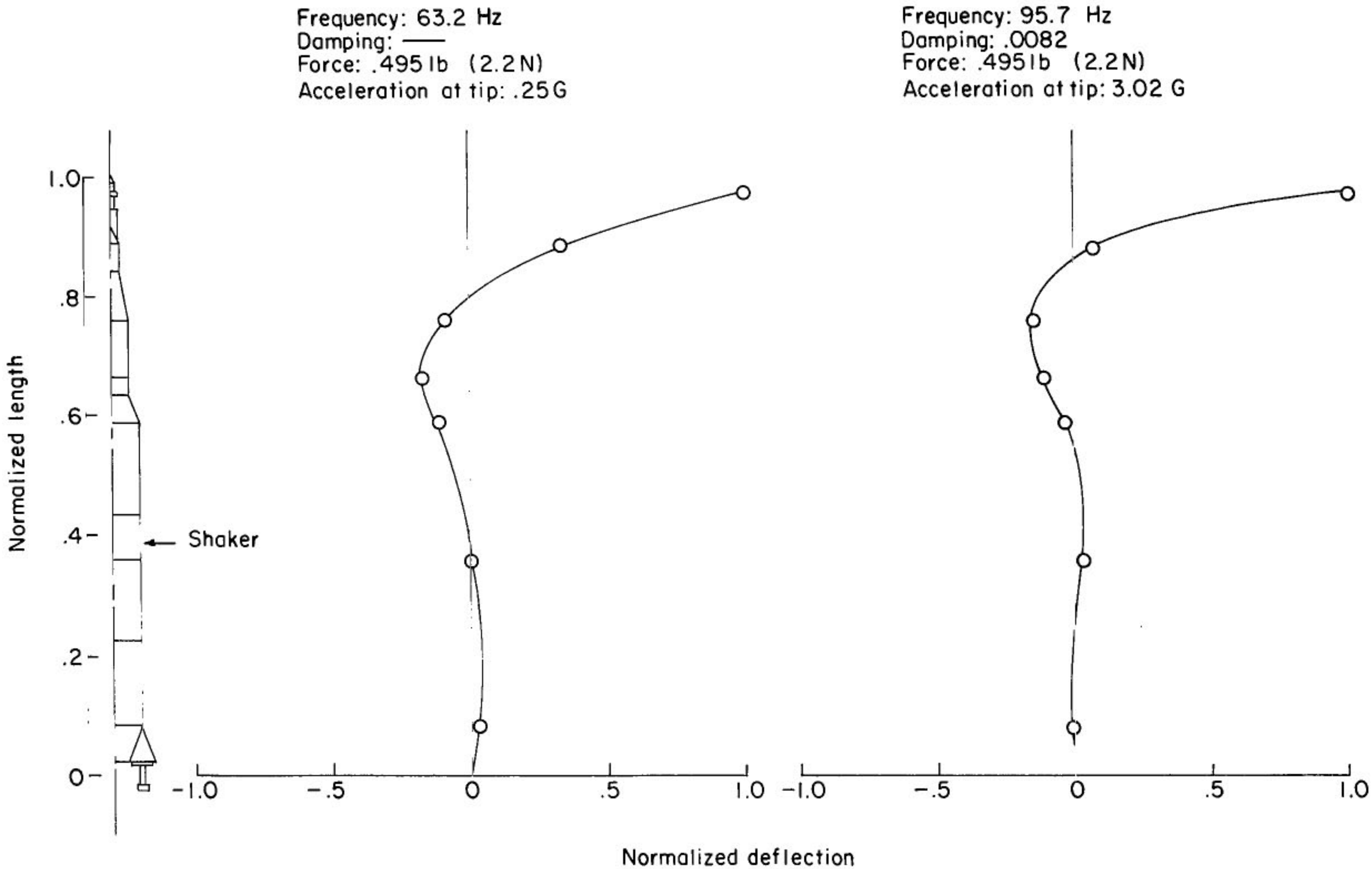
Figure 13.- Concluded.



(a) First mode.

(b) Second mode.

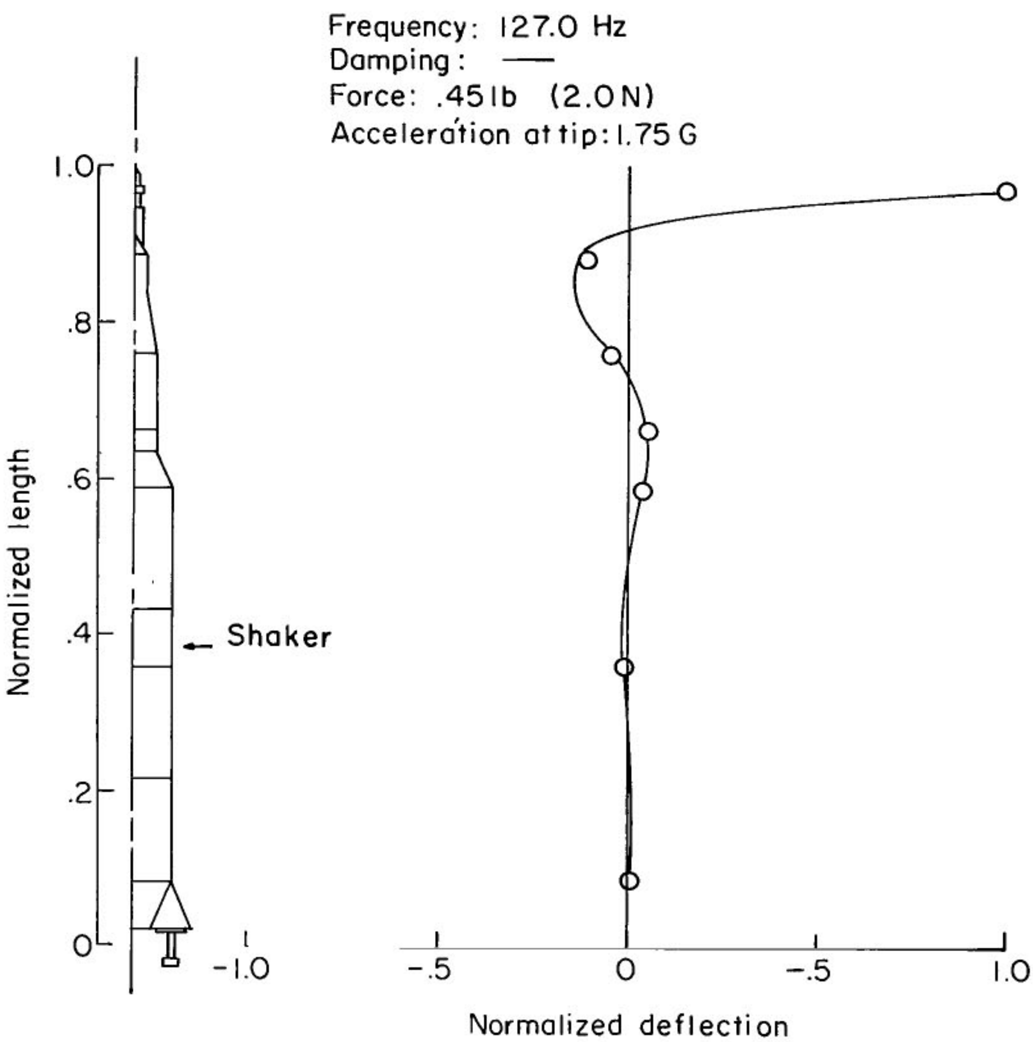
Figure 14.- Normalized cantilever mode shapes of the 1/40-scale Saturn V model in the fueled condition.



(c) Third mode.

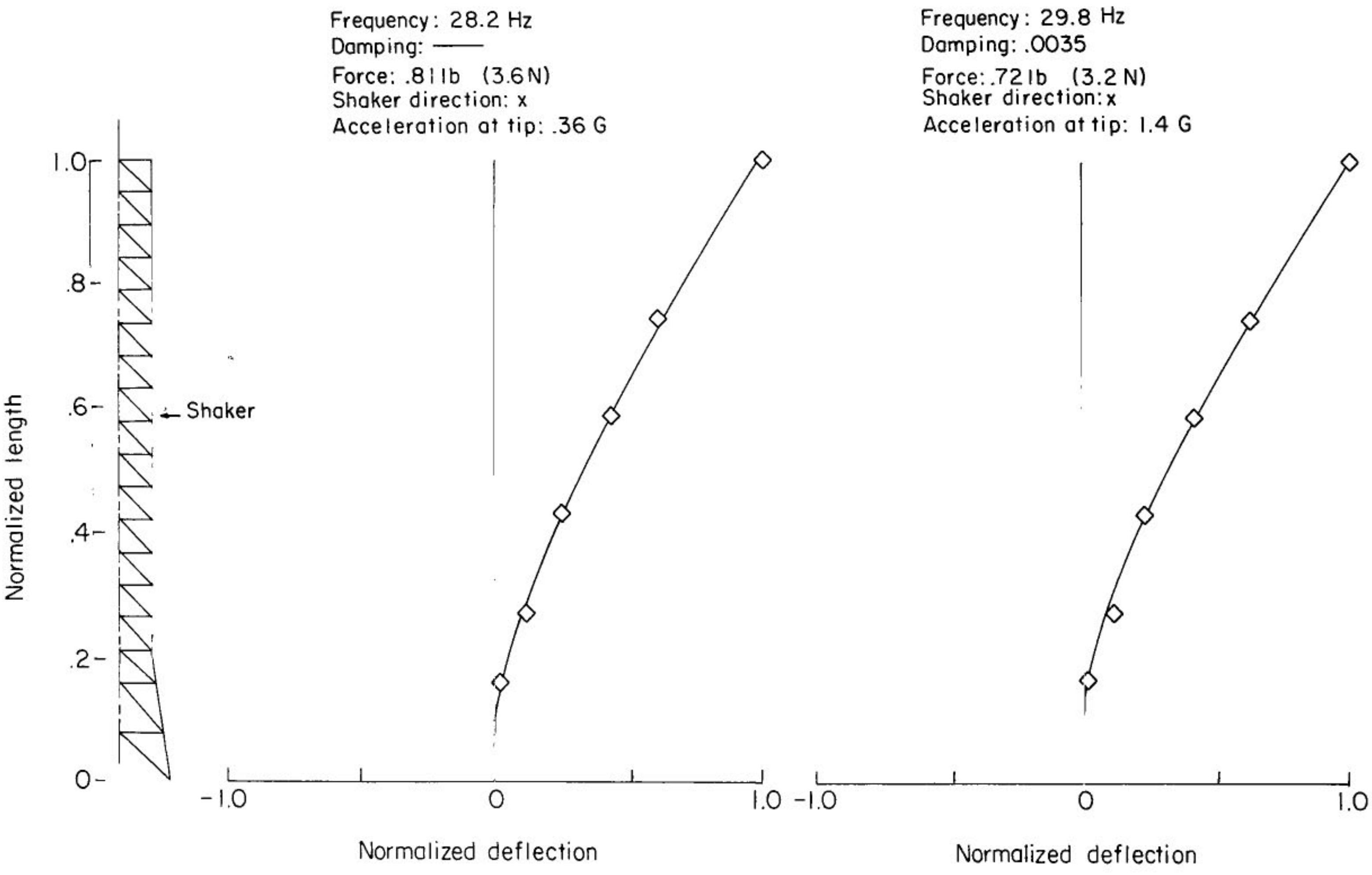
(d) Fourth mode.

Figure 14.- Continued.



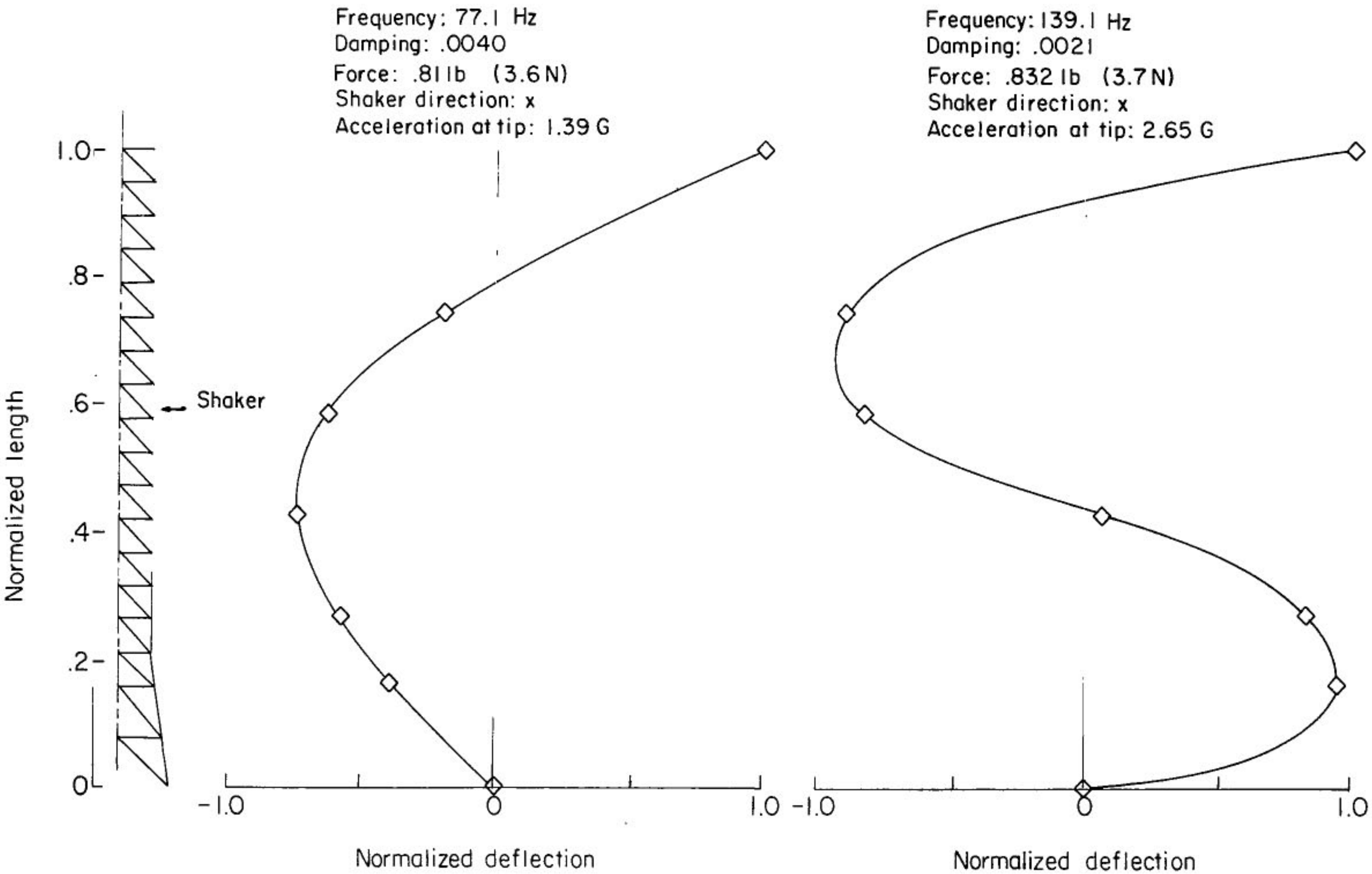
(e) Fifth mode.

Figure 14.- Concluded.



(a) First mode.

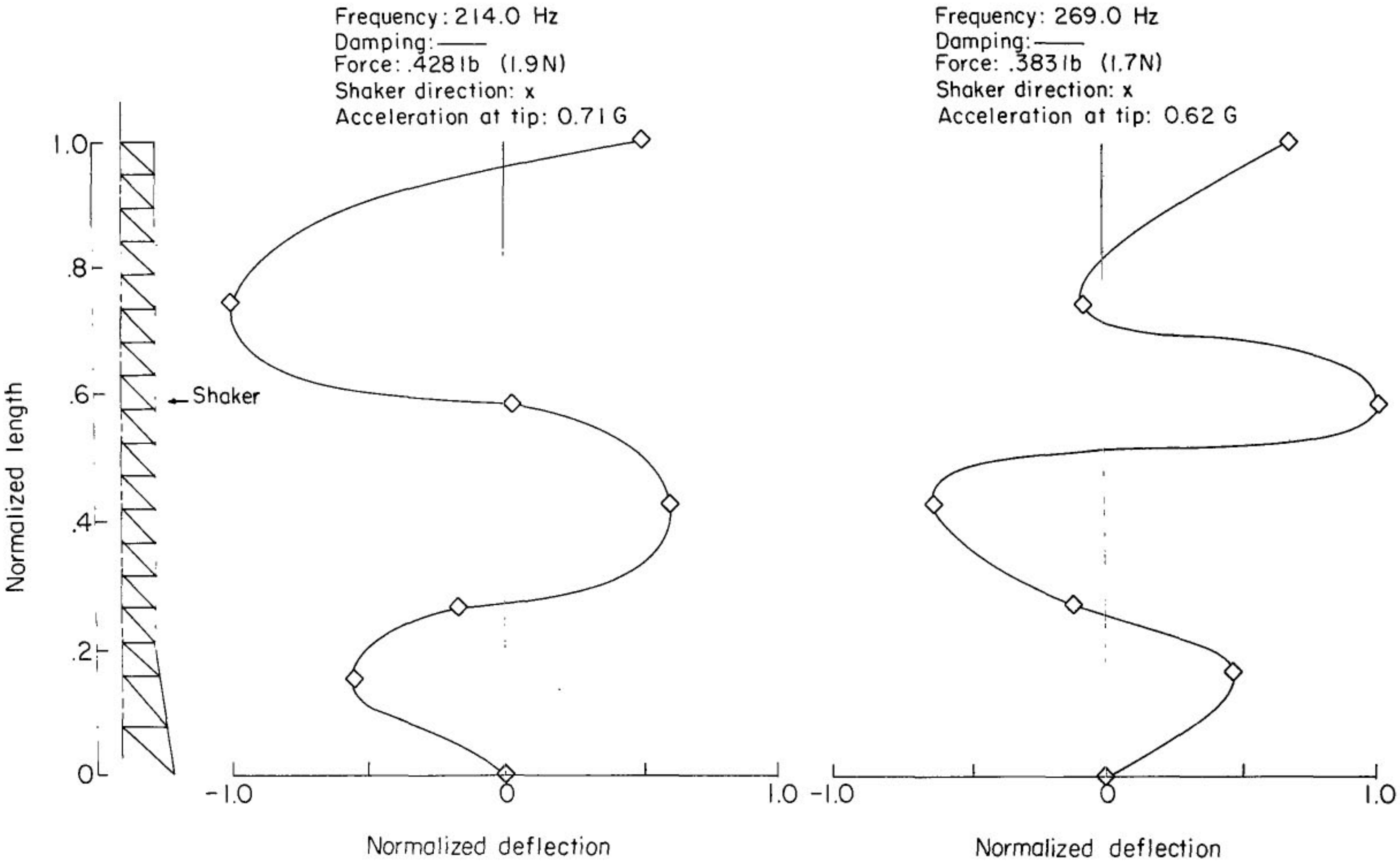
Figure 15.- Normalized cantilever mode shapes of the 1/40-scale tower model in the x-direction.



(b) Second mode.

(c) Third mode.

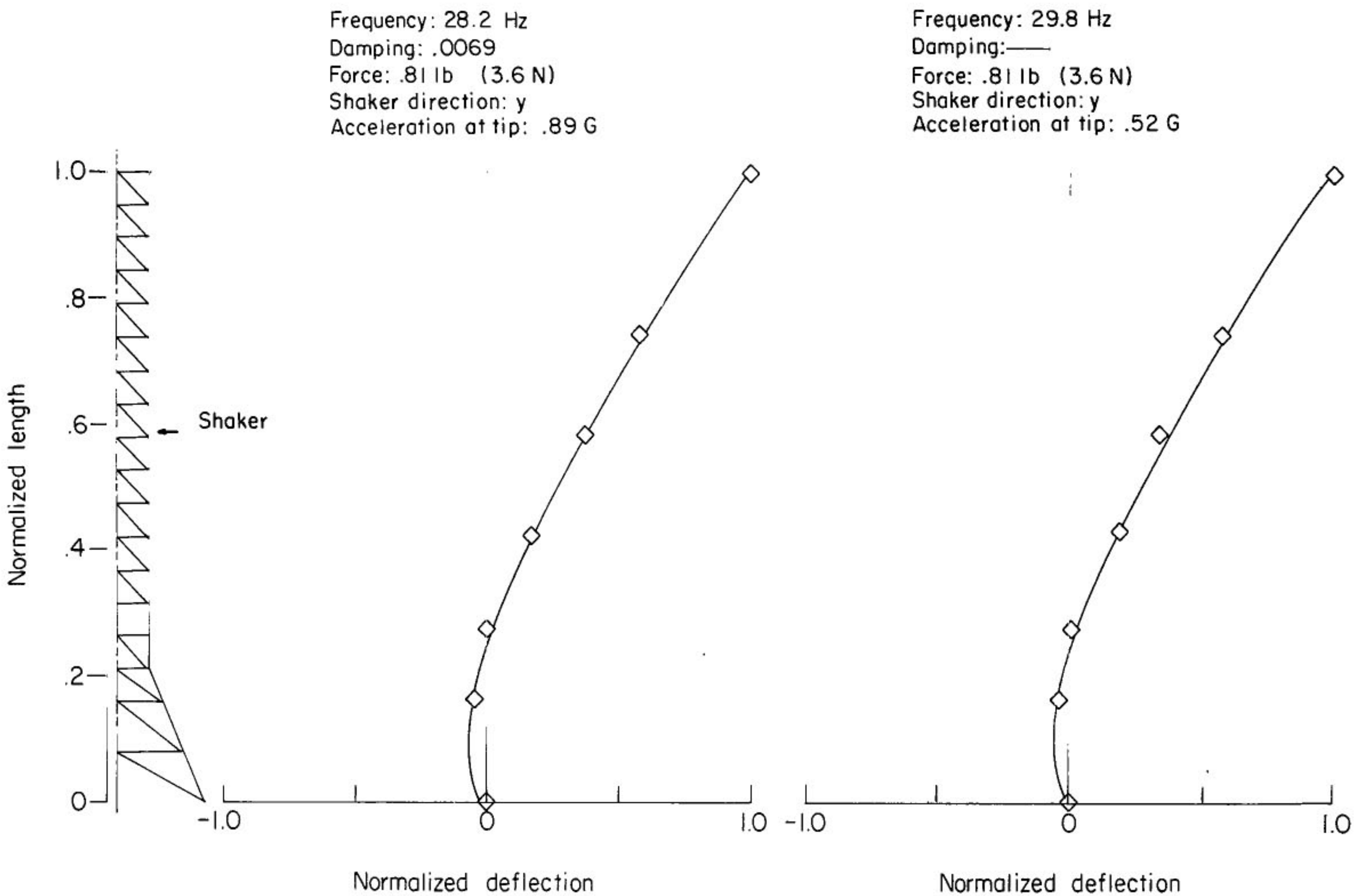
Figure 15.- Continued.



(d) Fourth mode.

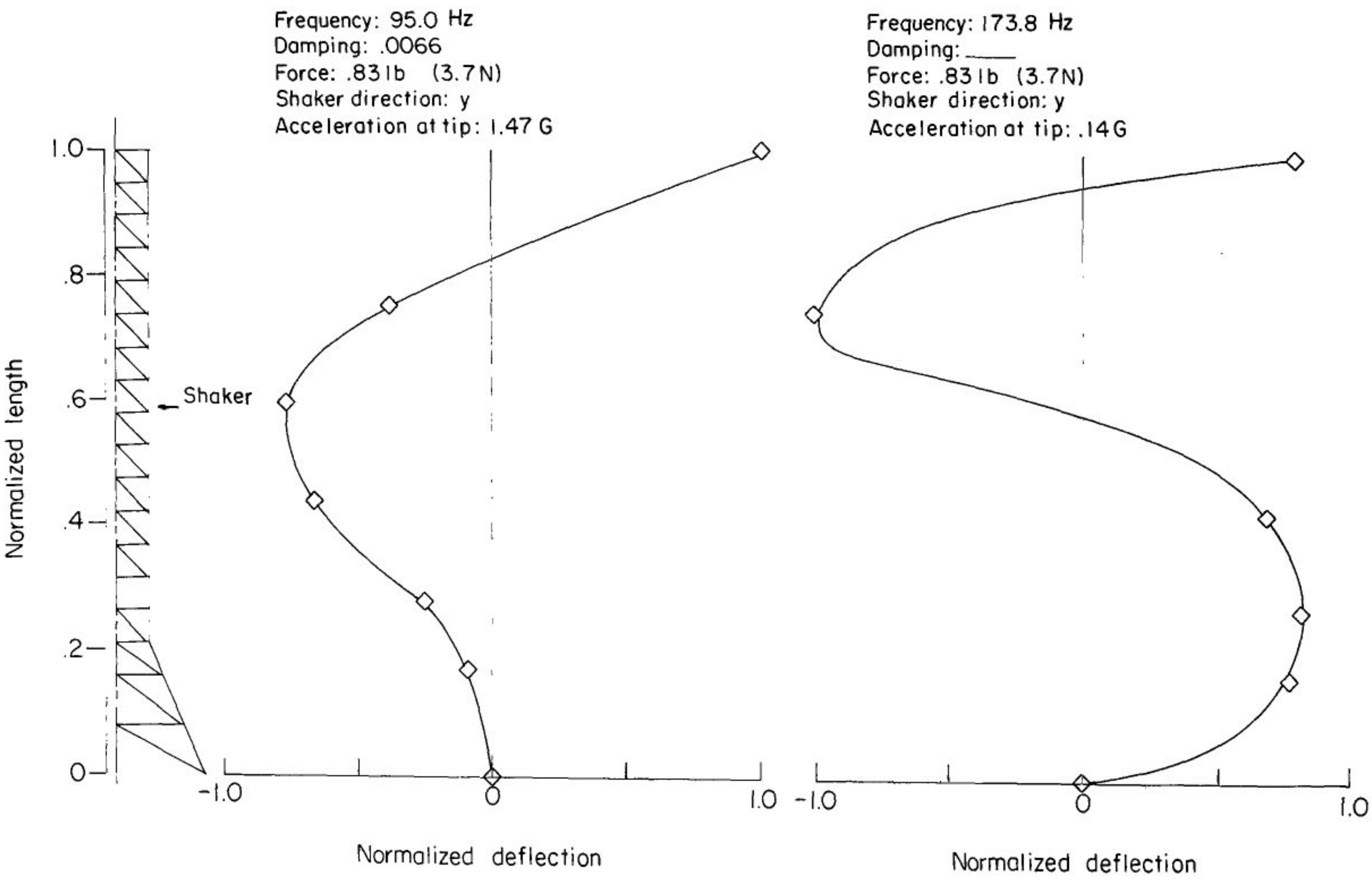
(e) Fifth mode.

Figure 15.- Concluded.



(a) First mode.

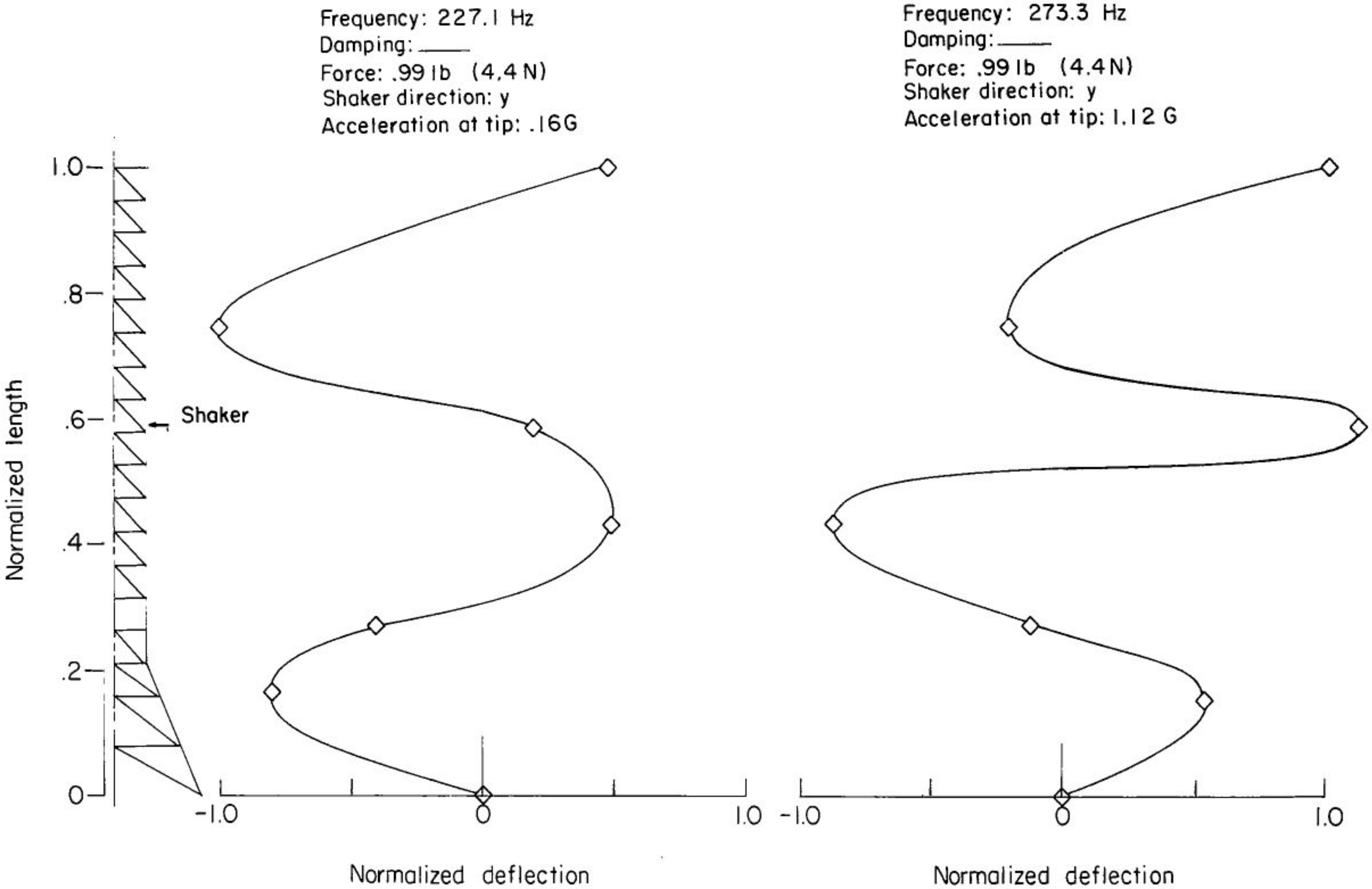
Figure 16.- Normalized cantilever mode shapes of the 1/40-scale tower model in the y-direction.



(b) Second mode.

(c) Third mode.

Figure 16.- Continued.



(d) Fourth mode.

(e) Fifth mode.

Figure 16.- Concluded.

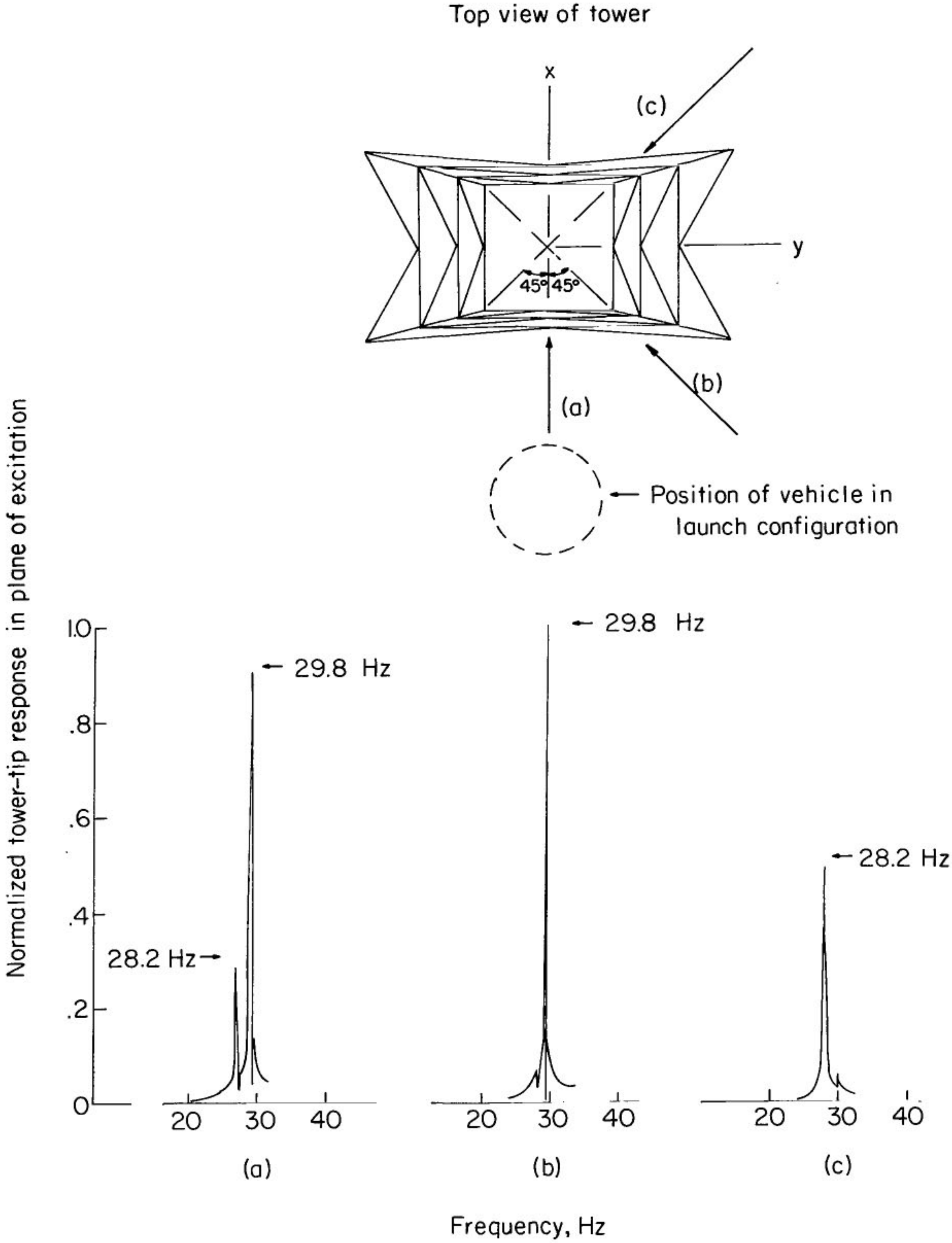


Figure 17.- First frequency response measured at tower-model tip with variable plane of excitation. (Plots (a), (b), and (c) show the response measured when force was applied in the directions indicated on the sketch by arrows labeled (a), (b), and (c).)

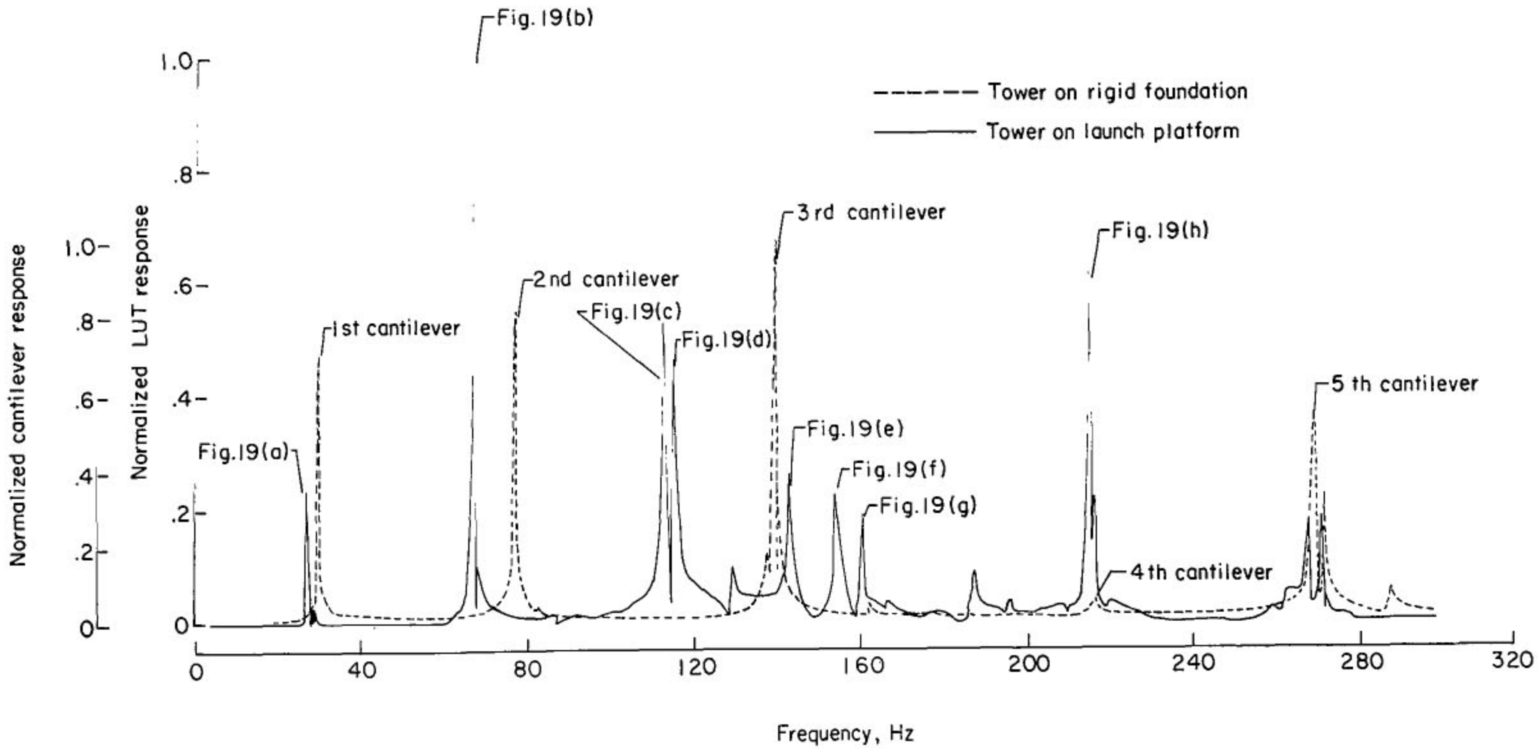
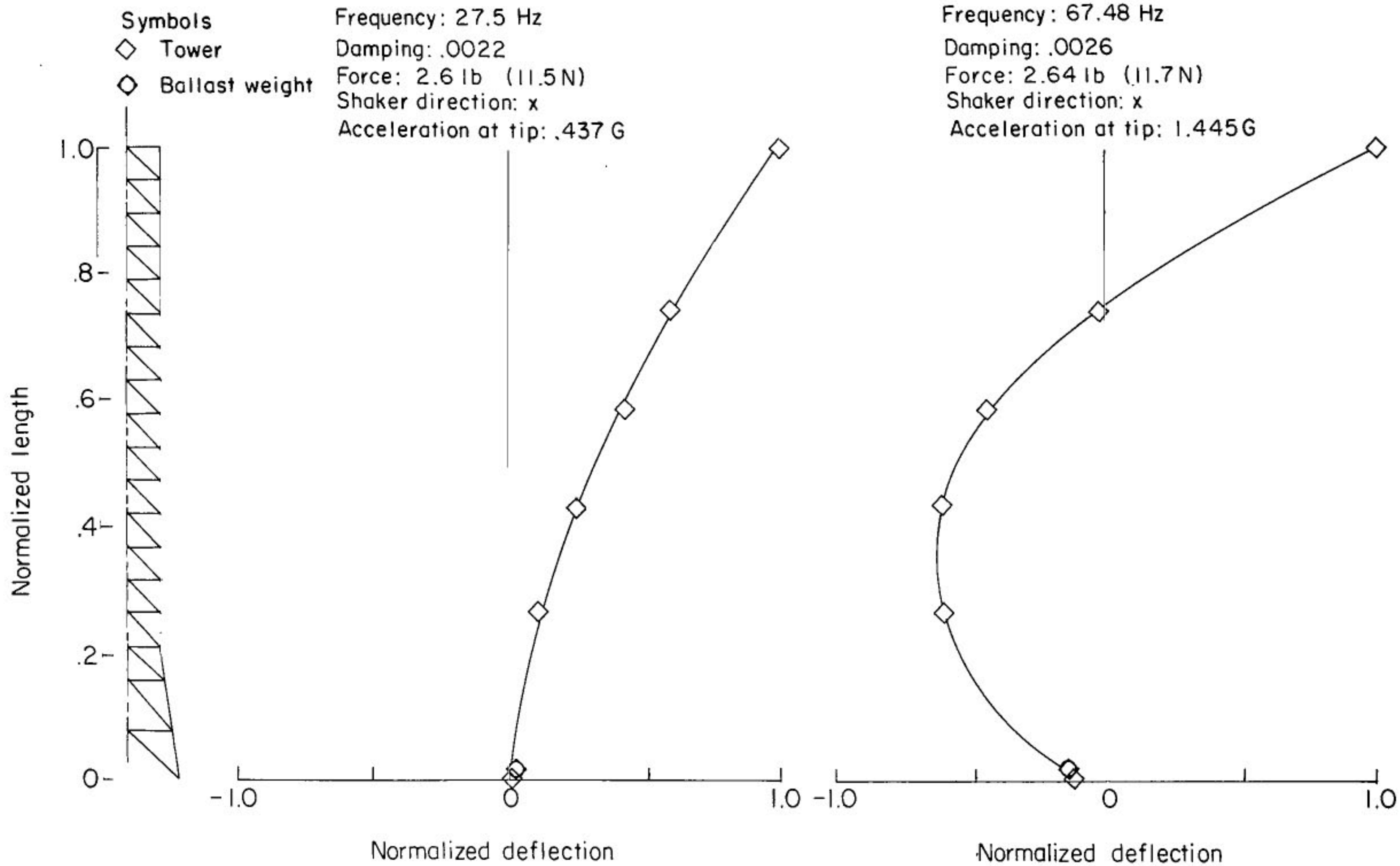


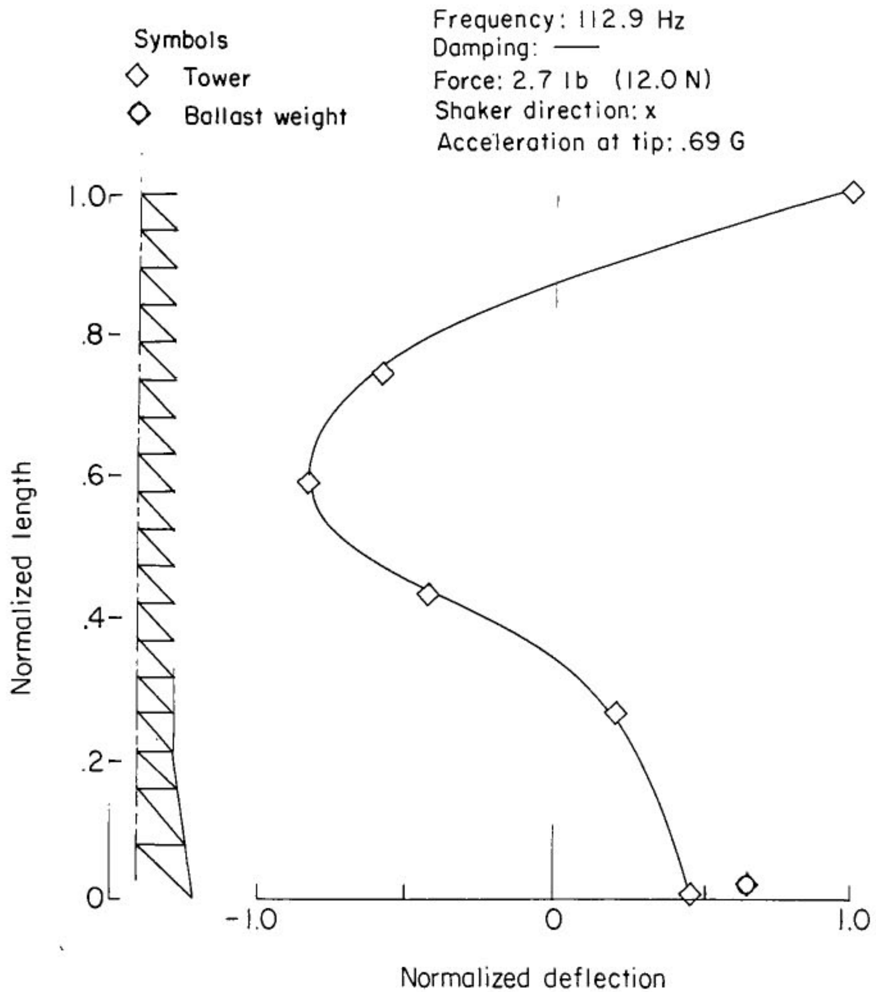
Figure 18.- Comparison of cantilevered-tower and platform-tower frequency responses measured at tower-model tip in x-direction.



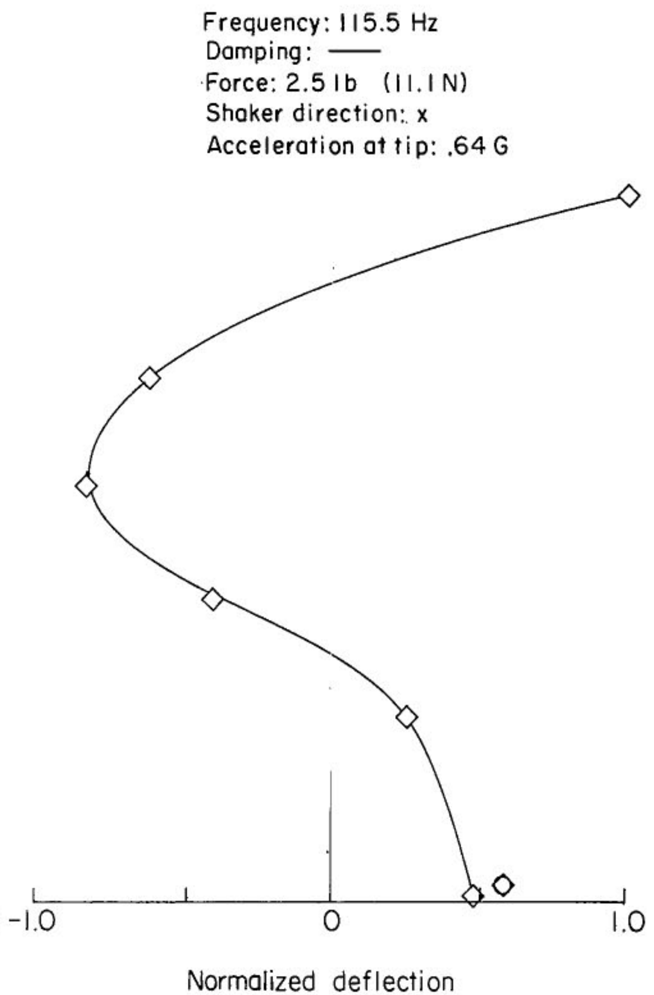
(a) First mode.

(b) Second mode.

Figure 19.- Normalized mode shapes of 1/40-scale tower mounted on launch platform without Saturn V model and with shaker oriented to apply force in x-direction.

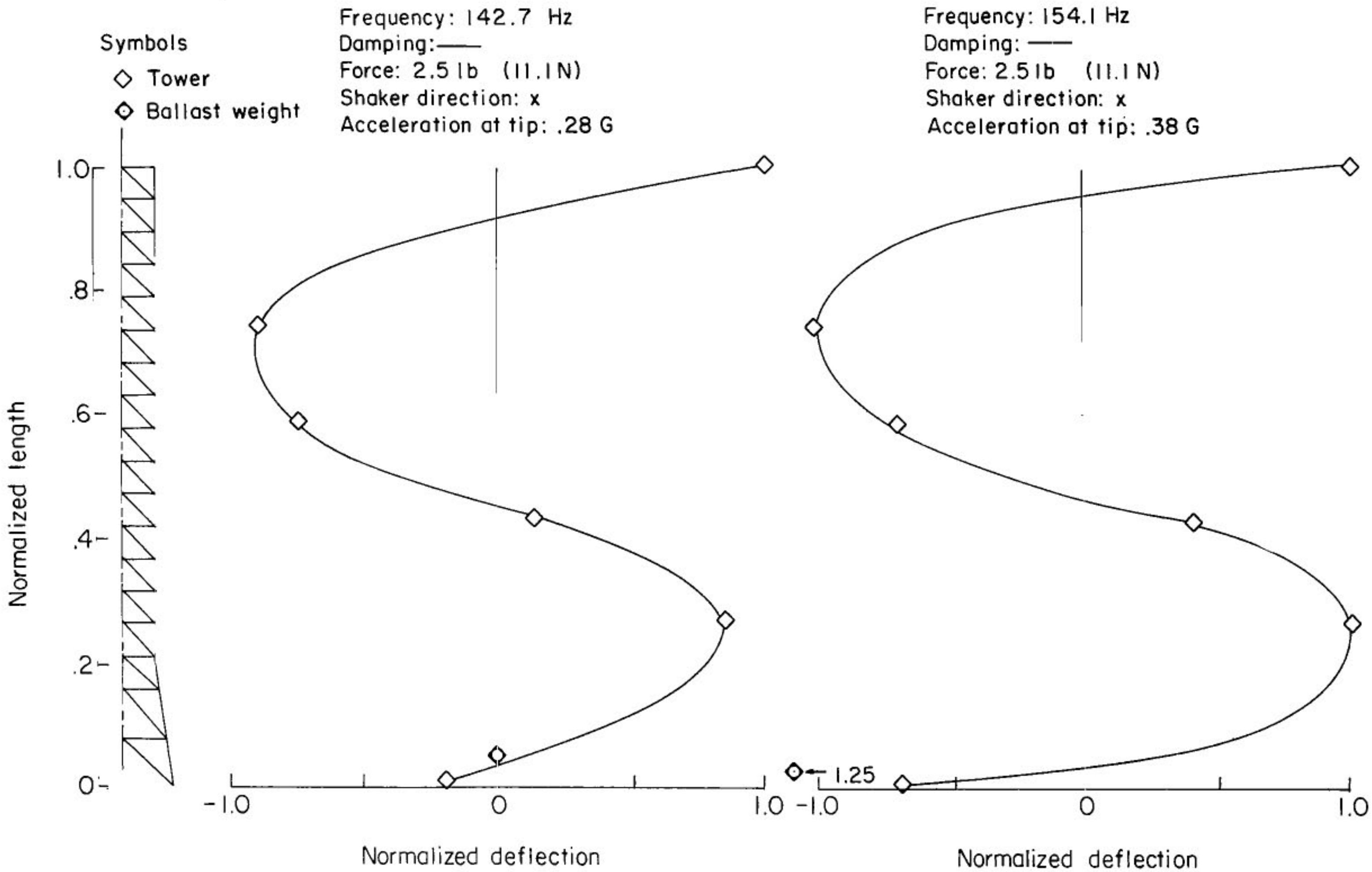


(c) Third mode.



(d) Fourth mode.

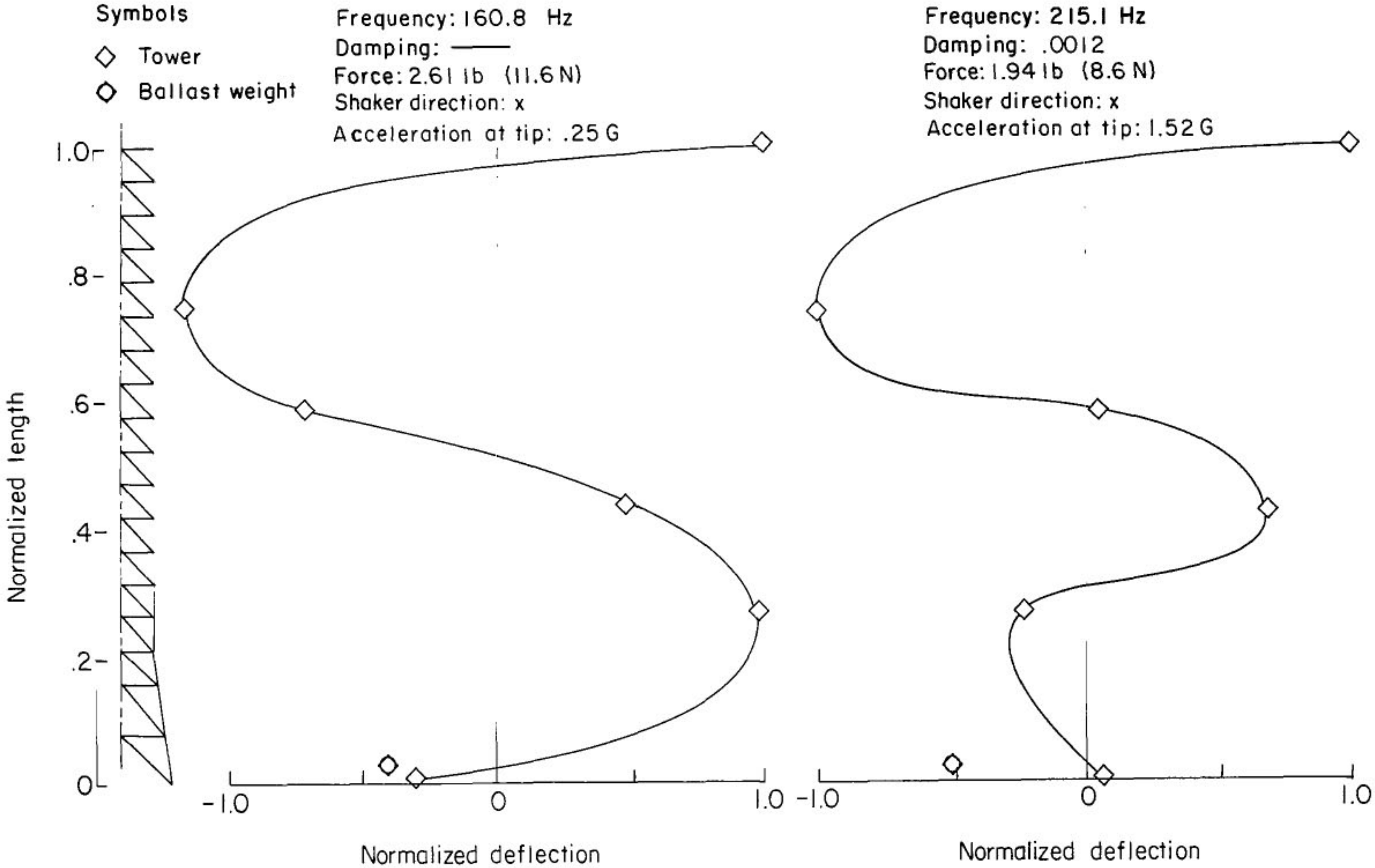
Figure 19.- Continued.



(e) Fifth mode.

(f) Sixth mode.

Figure 19.- Continued.



(g) Seventh mode.

(h) Eighth mode.

Figure 19.- Concluded.

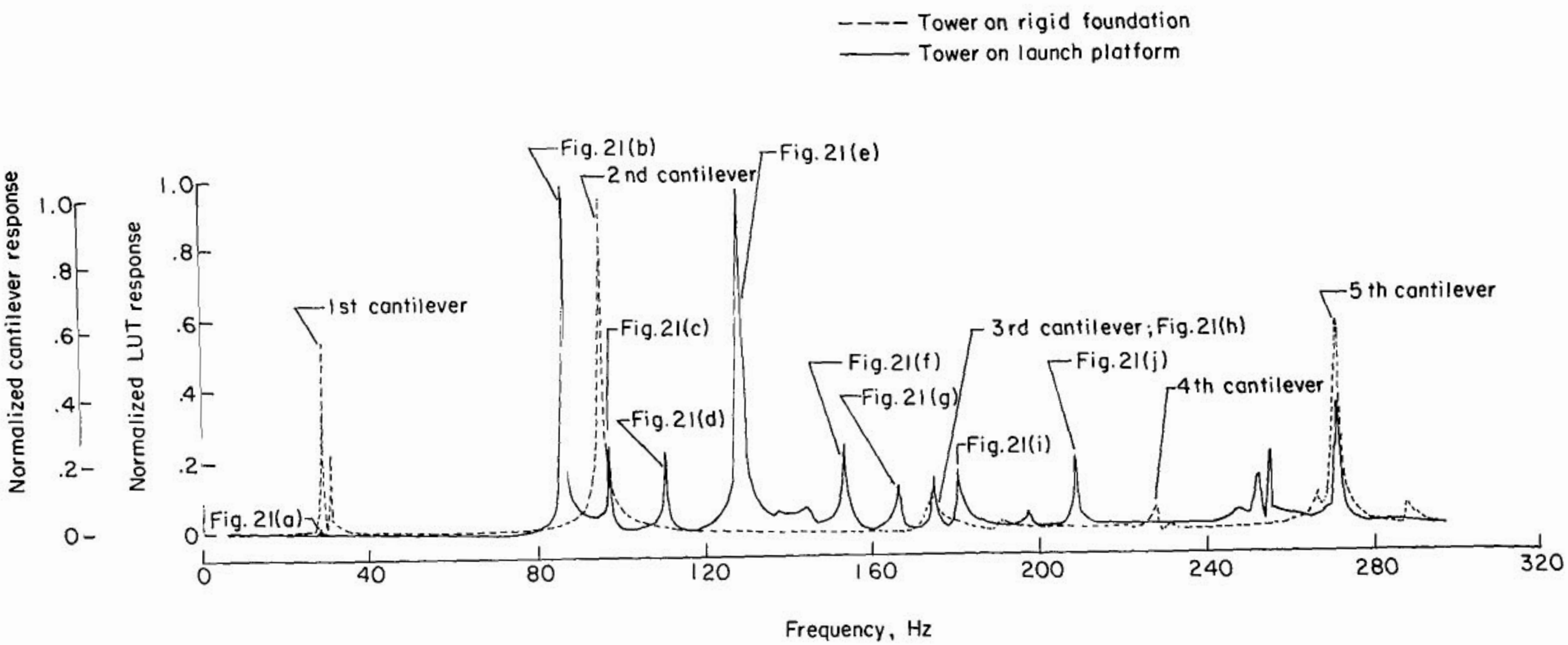
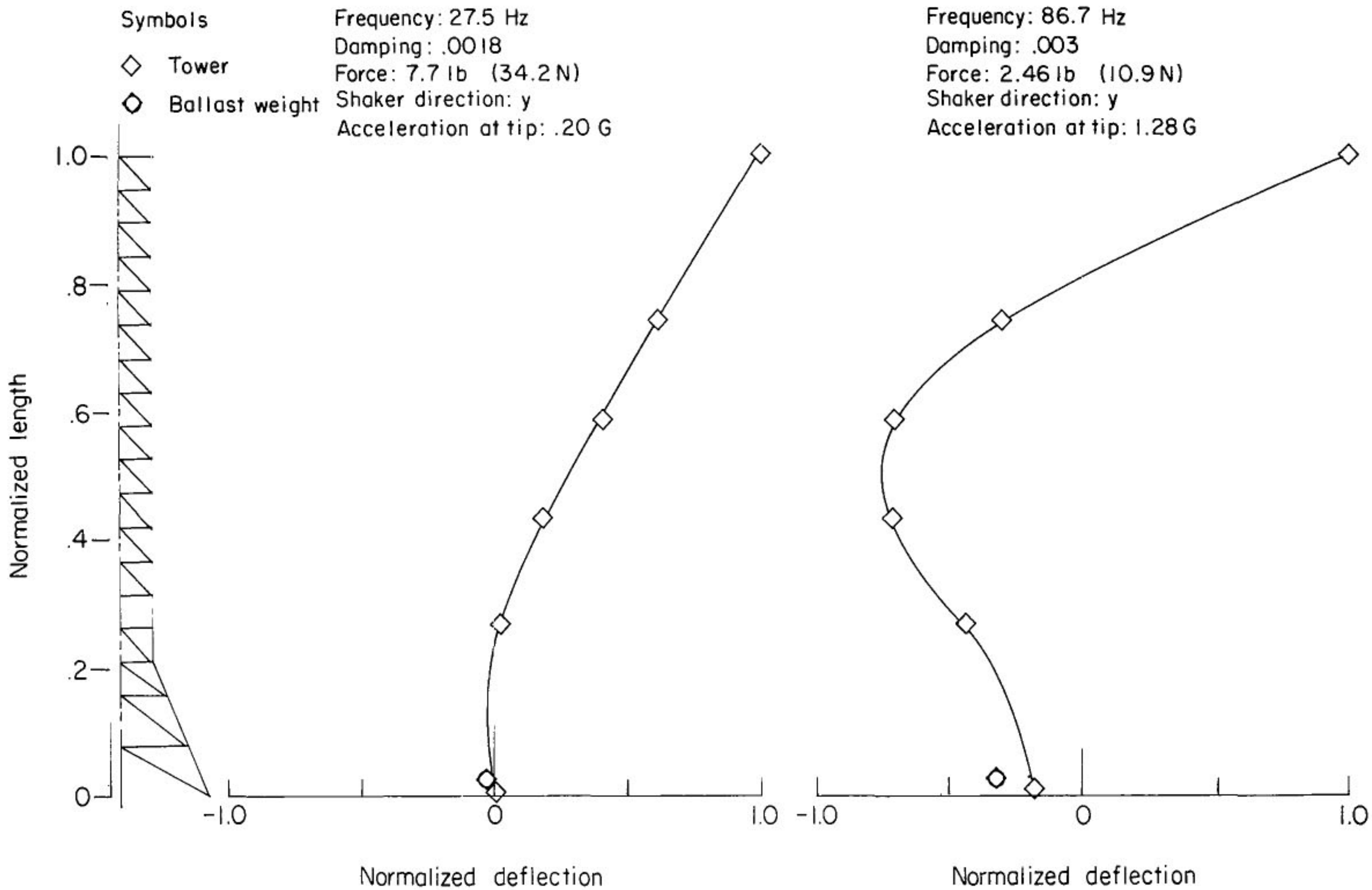


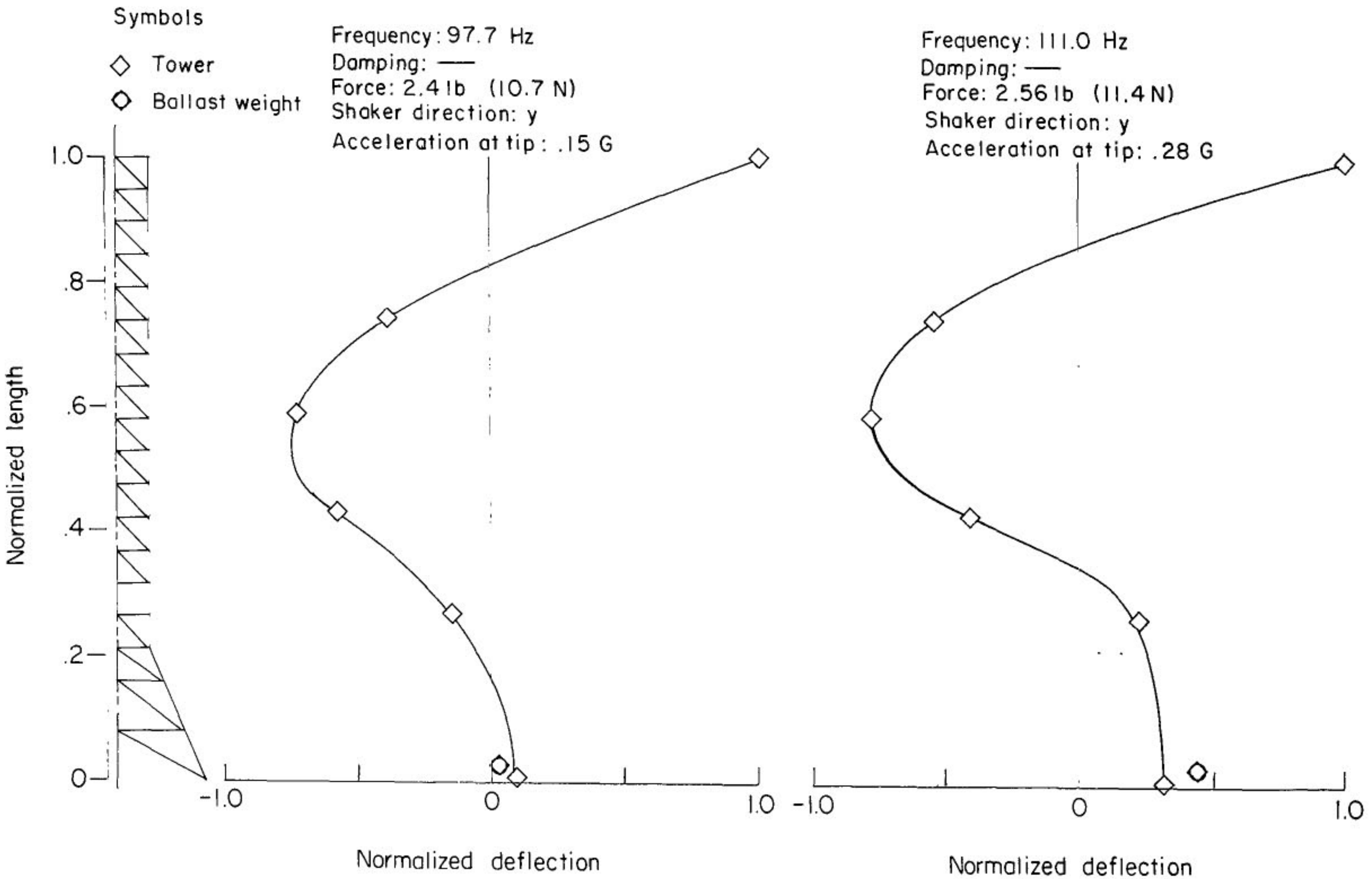
Figure 20.- Comparison of cantilevered-tower and platform-tower frequency responses measured at tower-model tip in y-direction.



(a) First mode.

(b) Second mode.

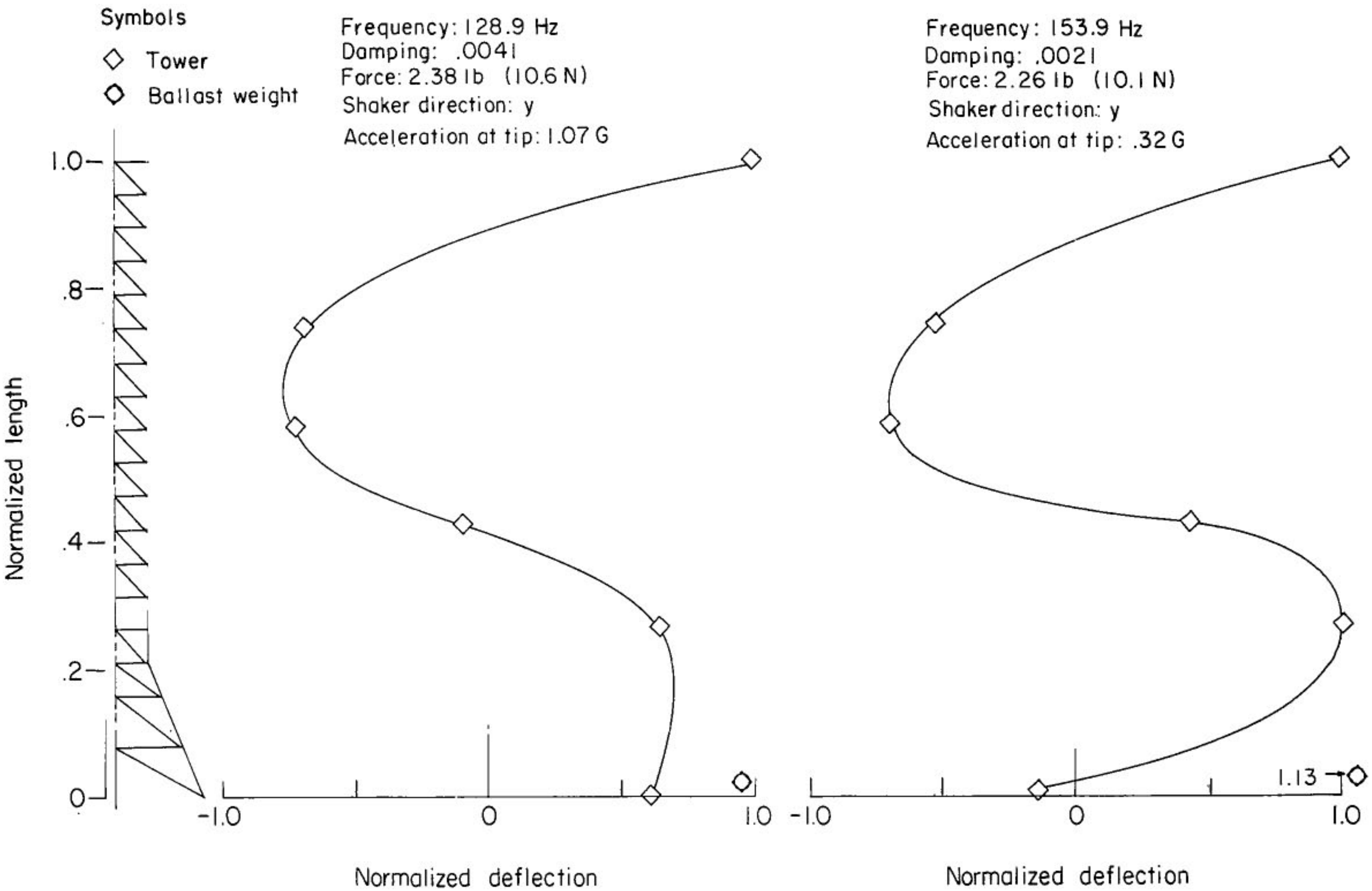
Figure 21.- Normalized mode shapes of 1/40-scale tower mounted on launch platform without Saturn V model and with shaker oriented to apply force in y-direction.



(c) Third mode.

(d) Fourth mode.

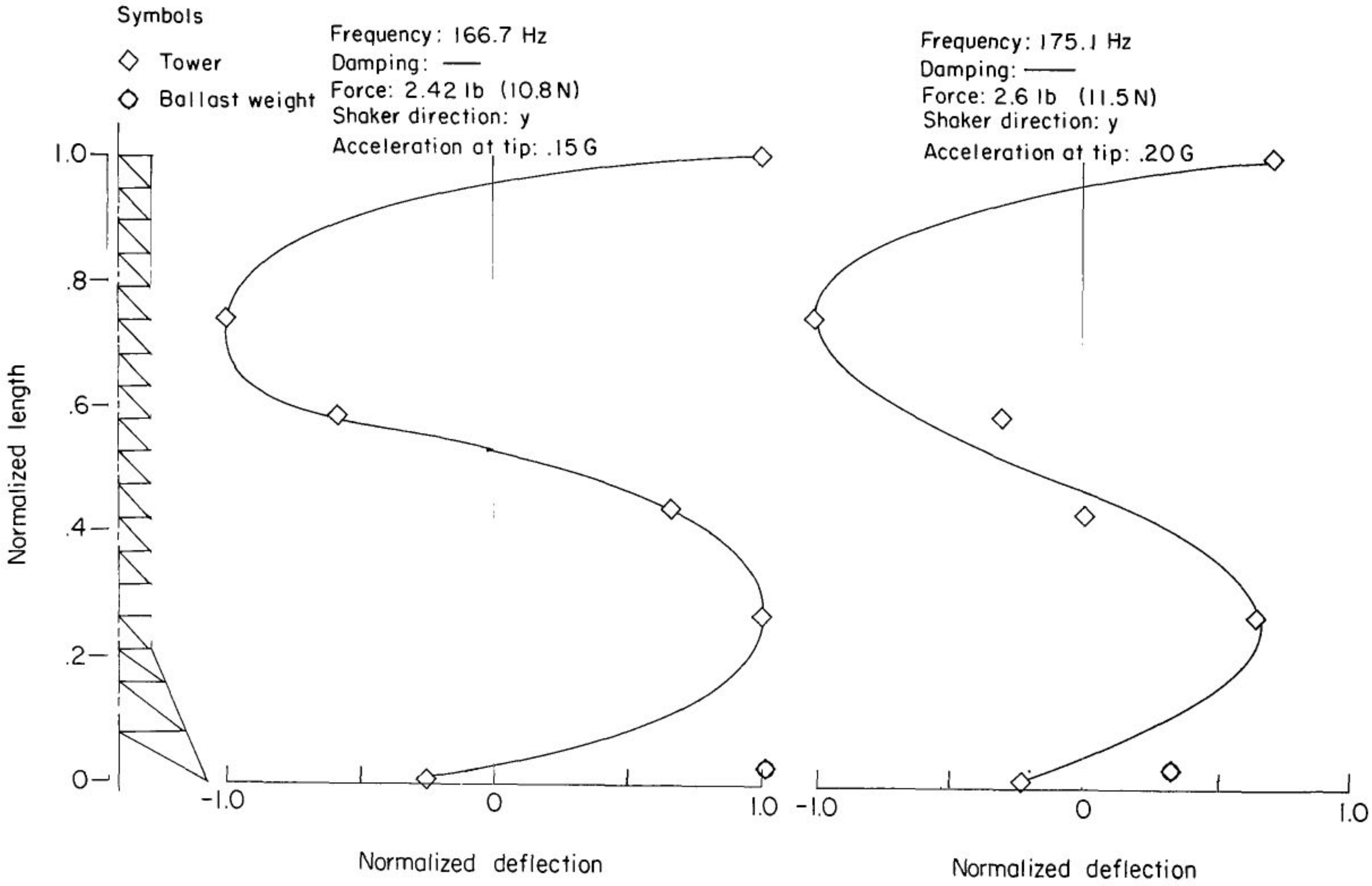
Figure 21.- Continued.



(e) Fifth mode.

(f) Sixth mode.

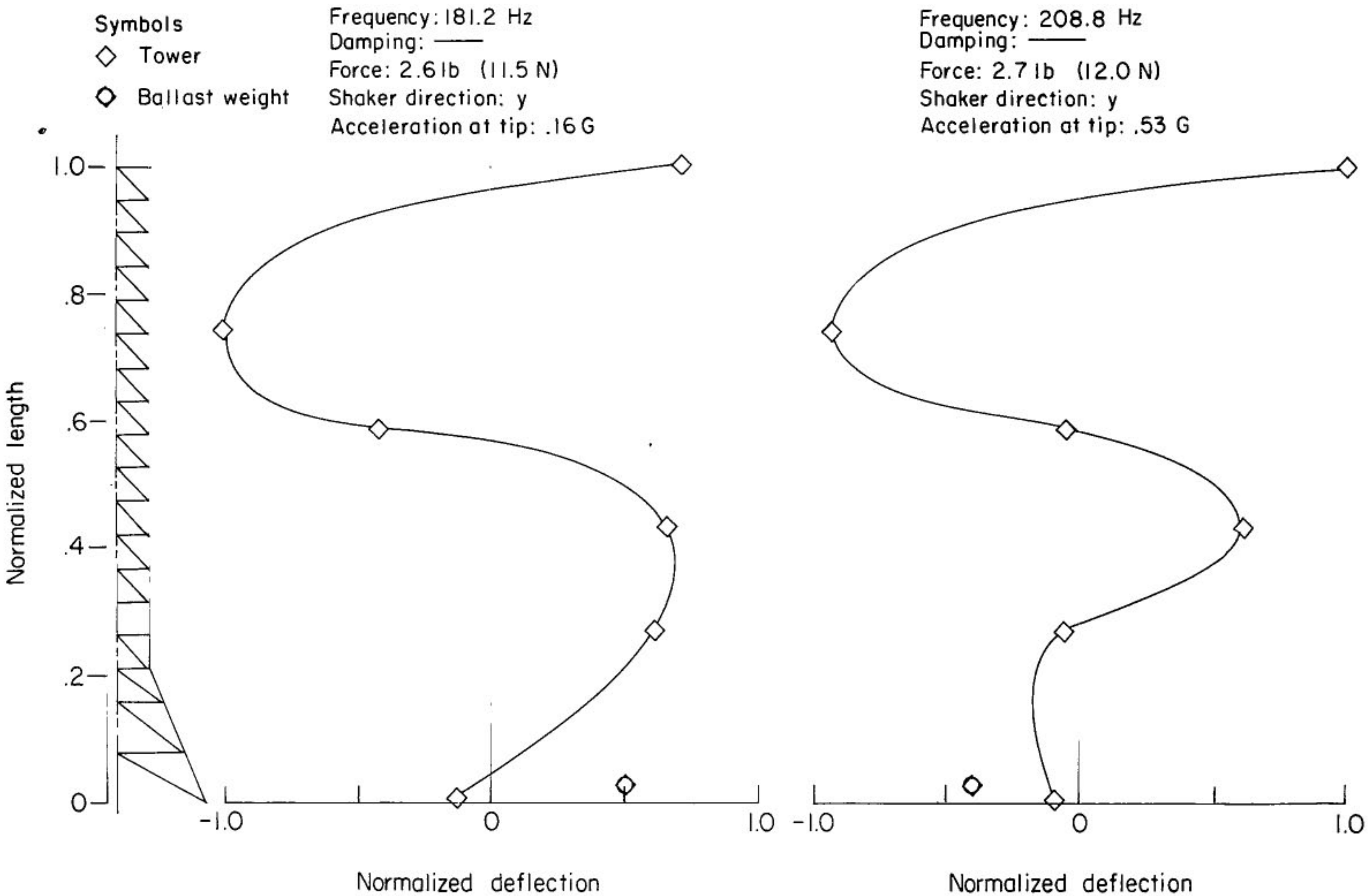
Figure 21.- Continued.



(g) Seventh mode.

(h) Eighth mode.

Figure 21.- Continued.



(i) Ninth mode.

(j) Tenth mode.

Figure 21.- Concluded.

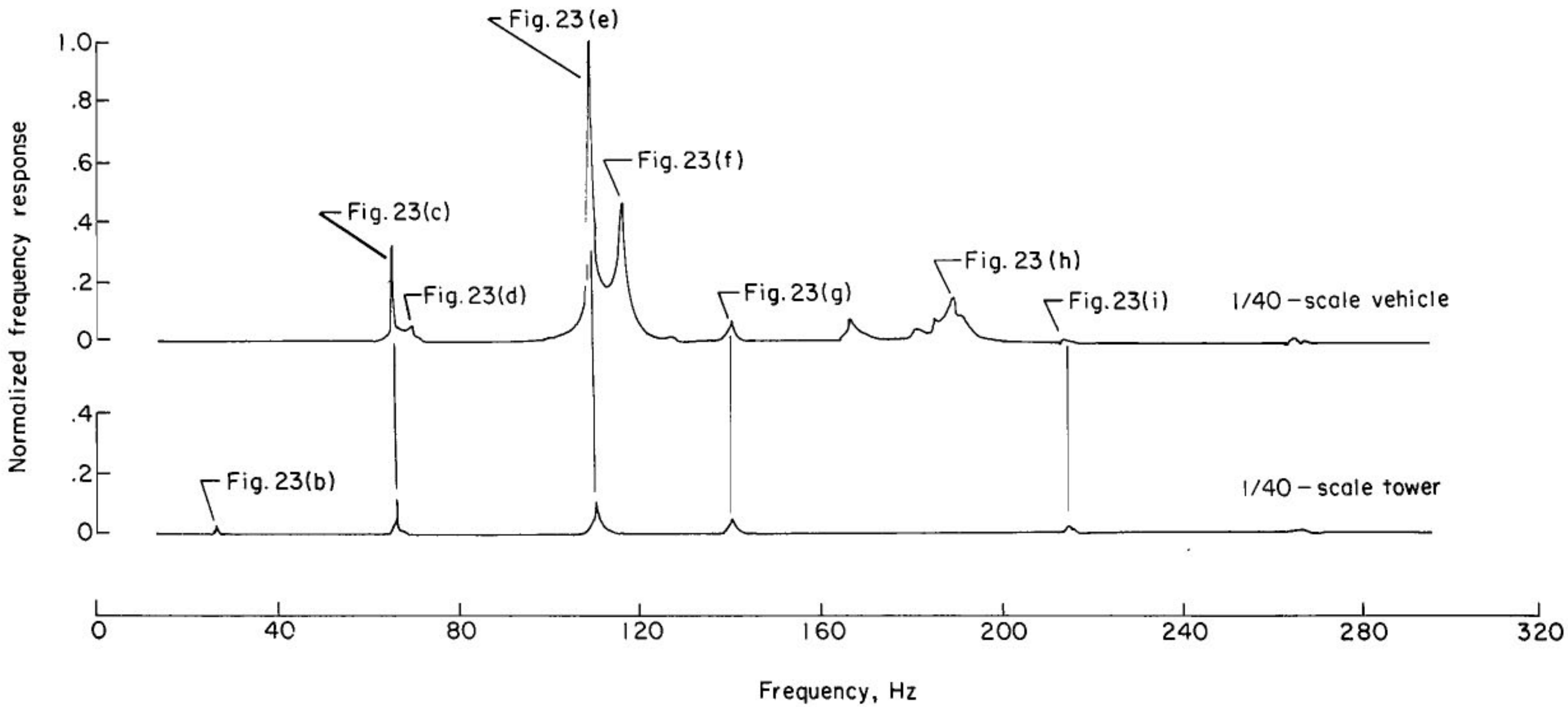
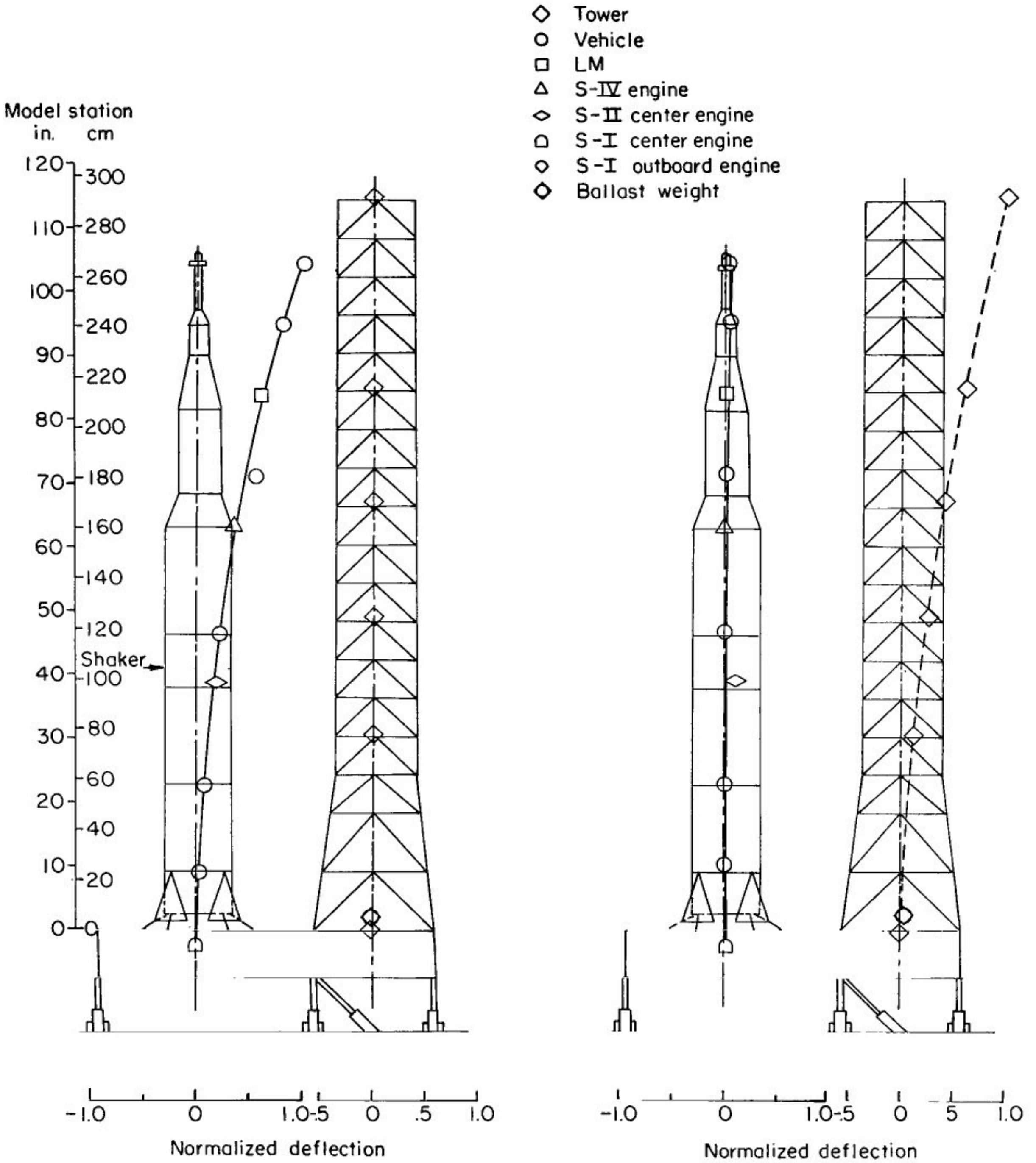


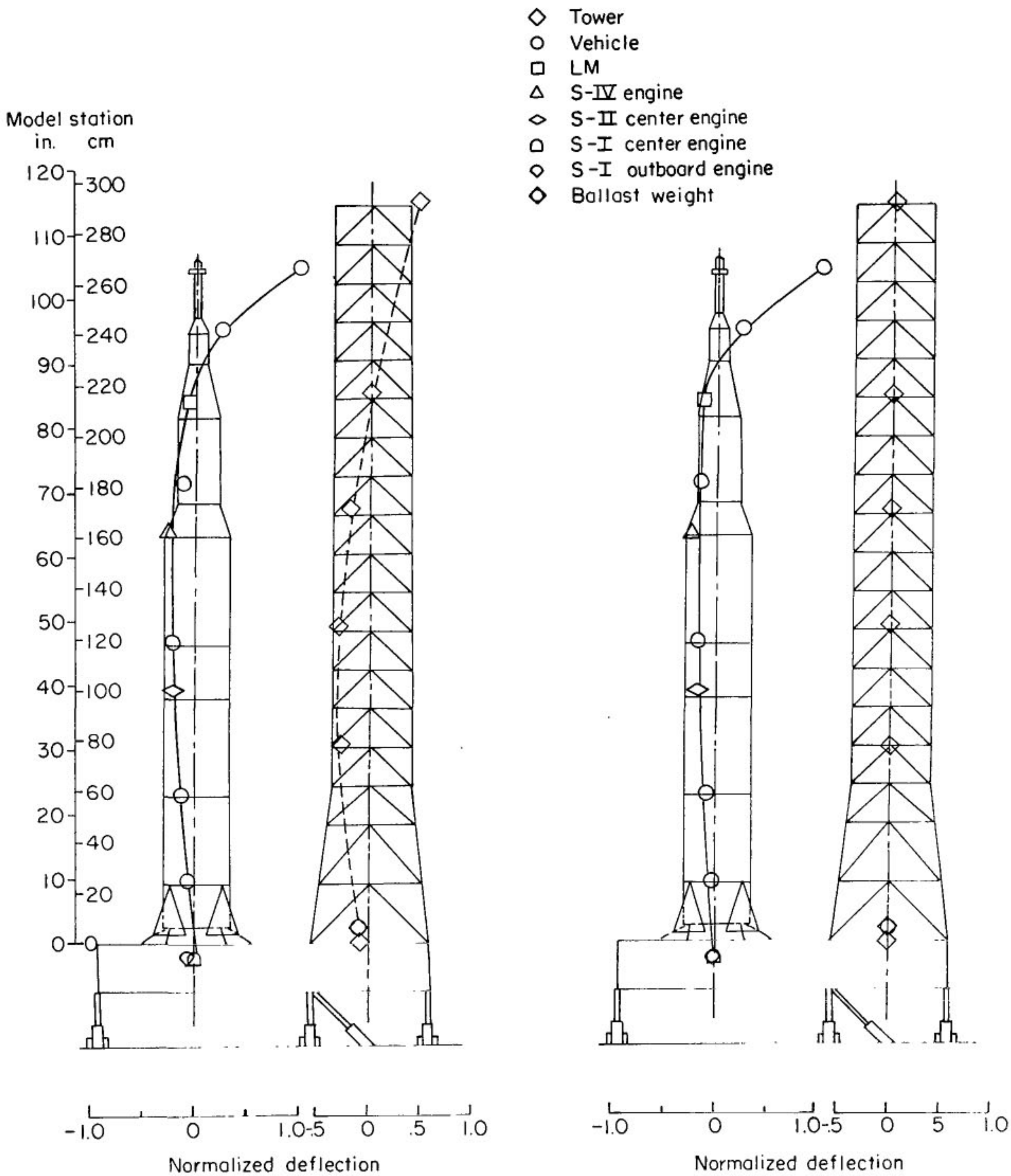
Figure 22.- Normalized frequency responses measured at tip of the unfueled Saturn V model and at tip of the tower with the shaker oriented to apply force in x-direction.



(a) First mode. f = 17.3 Hz; g_{MV} = 0.0083.

(b) Second mode. f = 27.3 Hz; g_{MT} = 0.0017.

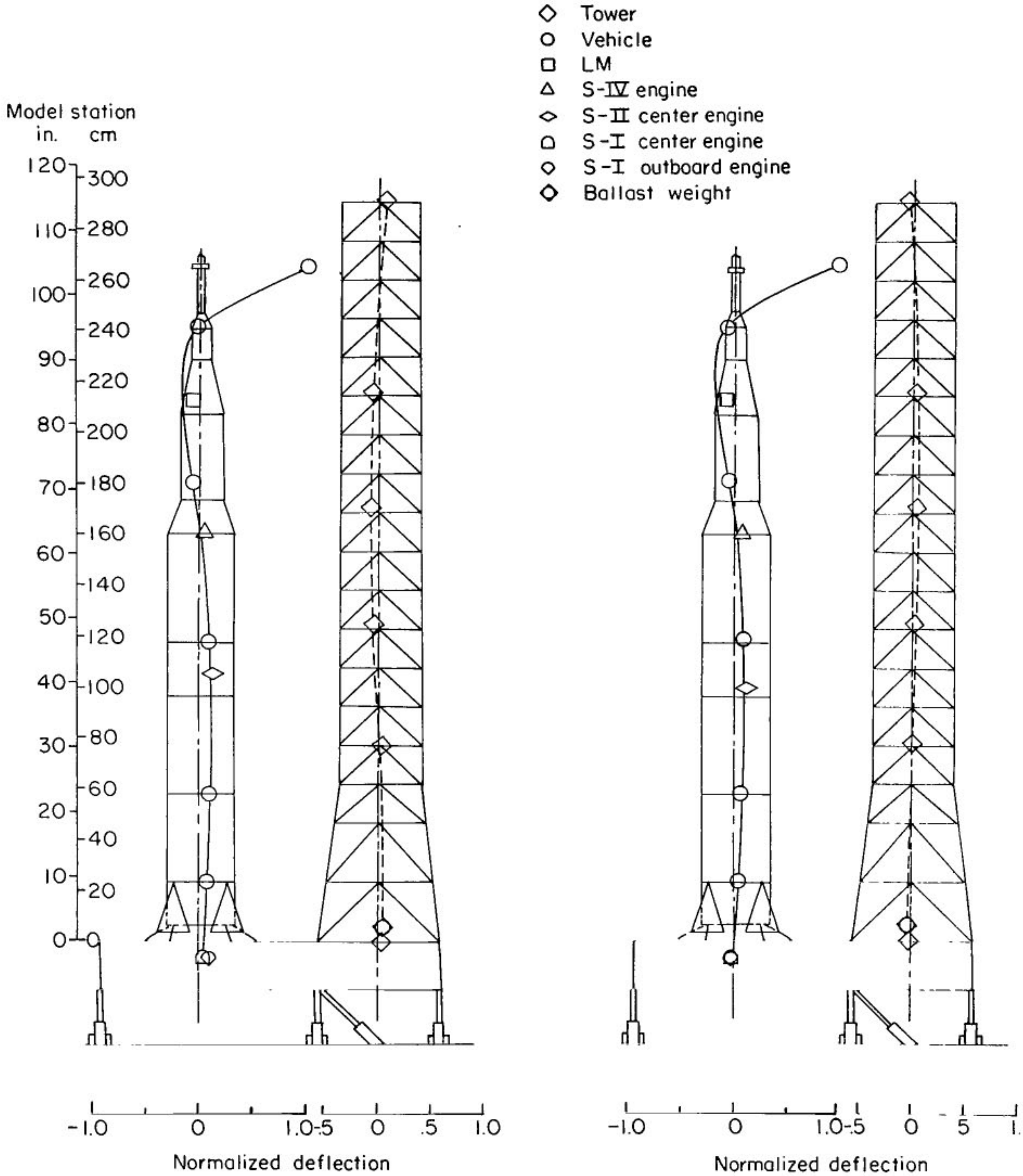
Figure 23.- Normalized mode shapes of 1/40-scale Saturn V-LUT configuration measured in x-direction with Saturn V model unfueled.



(c) Third mode. f = 66.1 Hz; g_{MV} = 0.0046, g_{MT} = 0.0091 to 0.003.

(d) Fourth mode. f = 70.7 Hz.

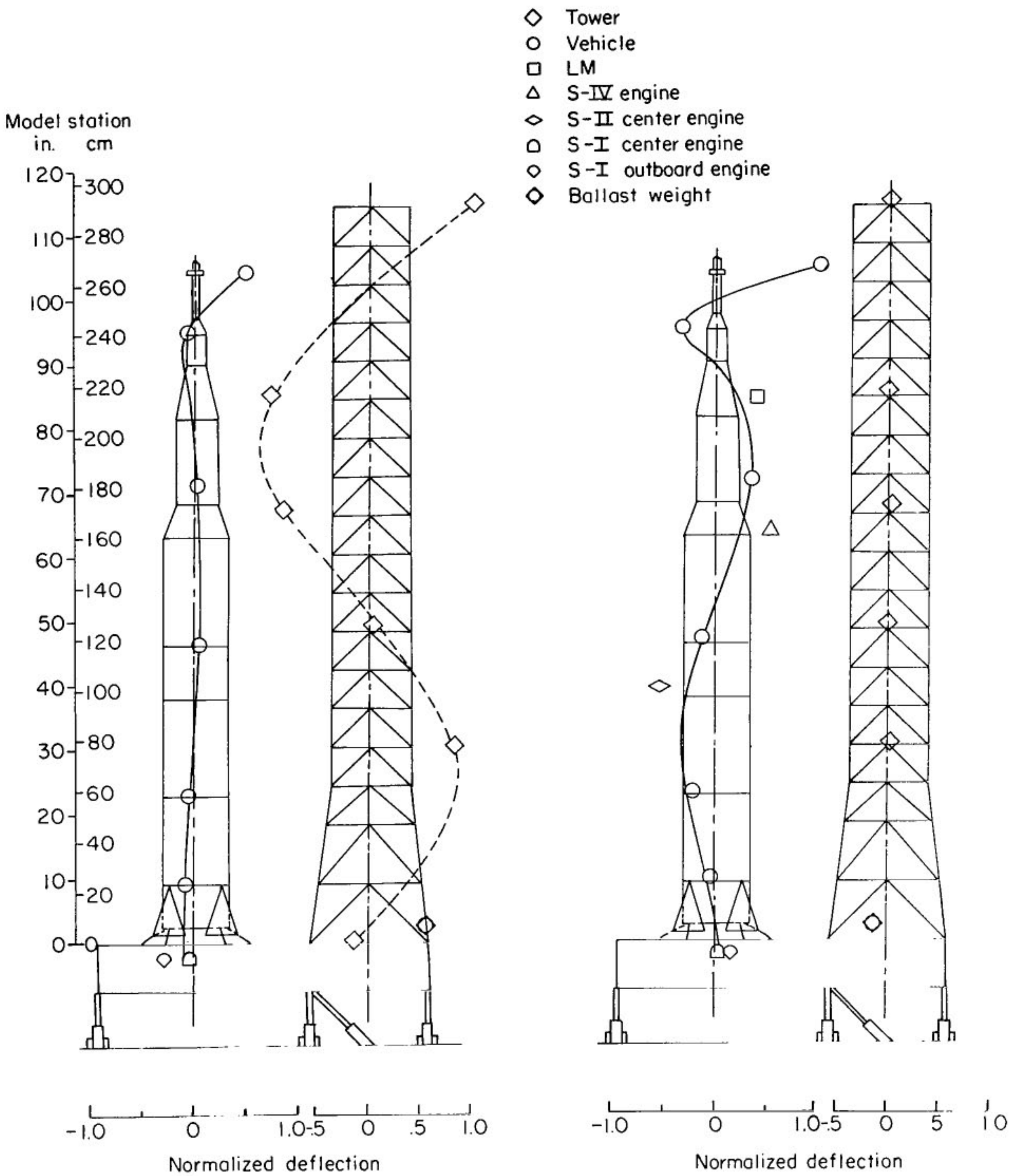
Figure 23.- Continued.



(e) Fifth mode. f = 109.3 Hz; g_{MT} = 0.0087 to 0.0058.

(f) Sixth mode. f = 115.5 Hz.

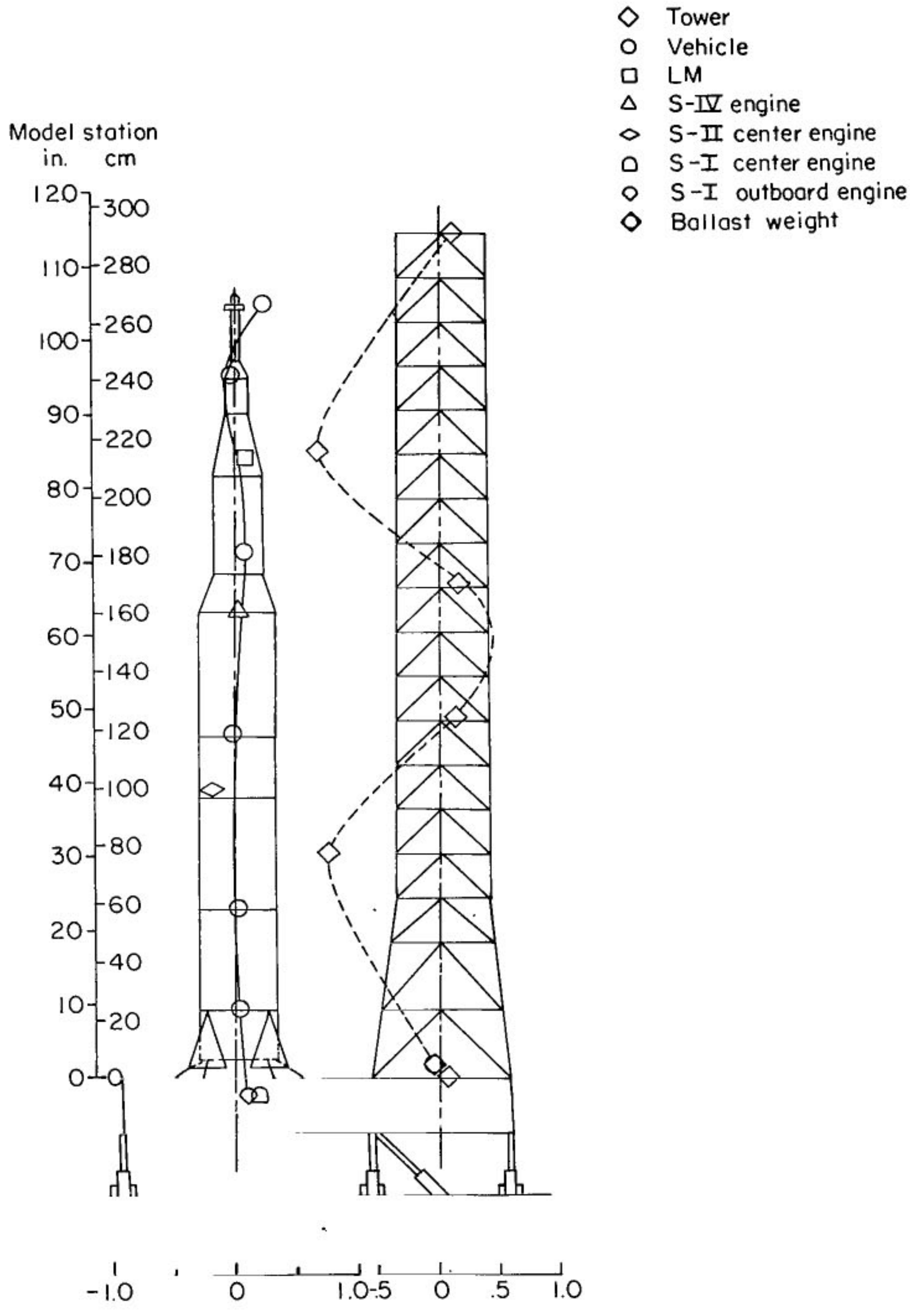
Figure 23.- Continued.



(g) Seventh mode. f = 140.1 Hz; g_{MT} = 0.012 to 0.003.

(h) Ninth mode. f = 189.8 Hz.

Figure 23.- Continued.



(i) Tenth mode. f = 213.7 Hz; g_{MT} = 0.0147.

Figure 23.- Concluded.

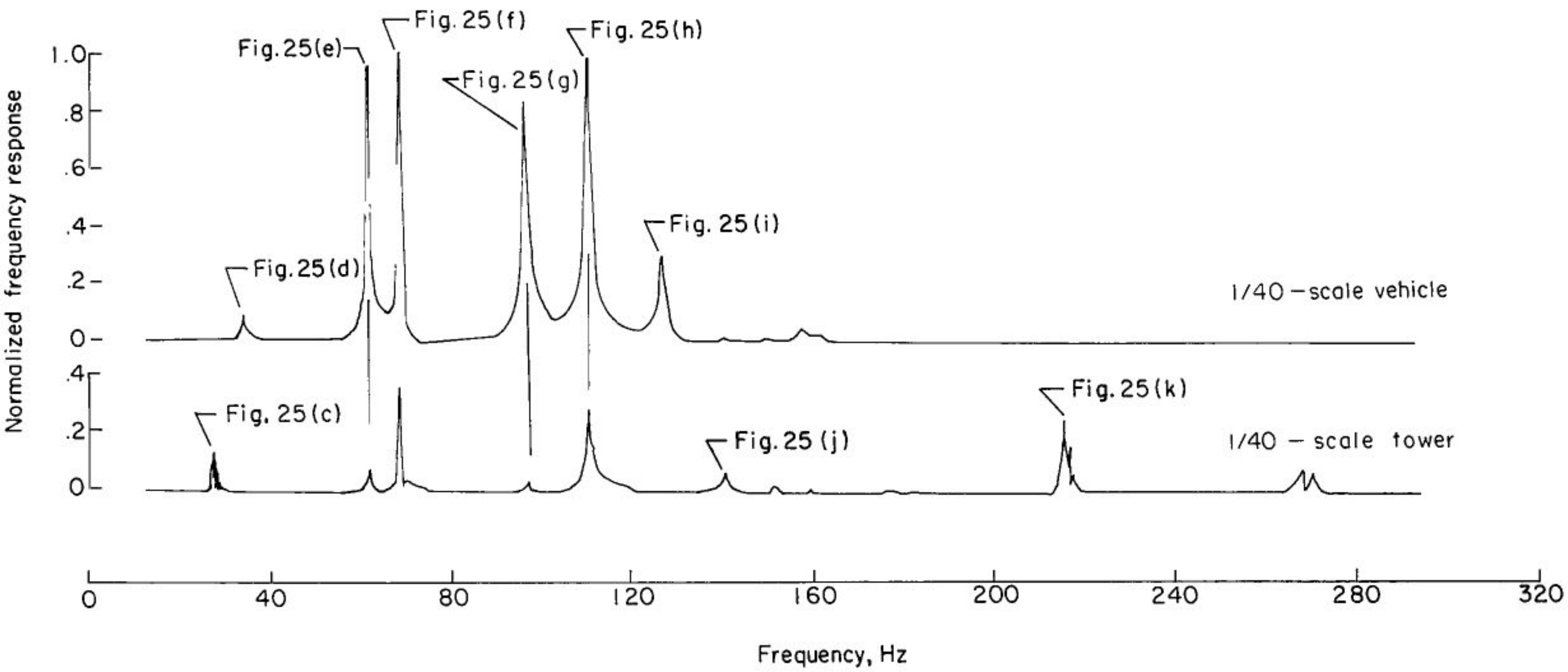
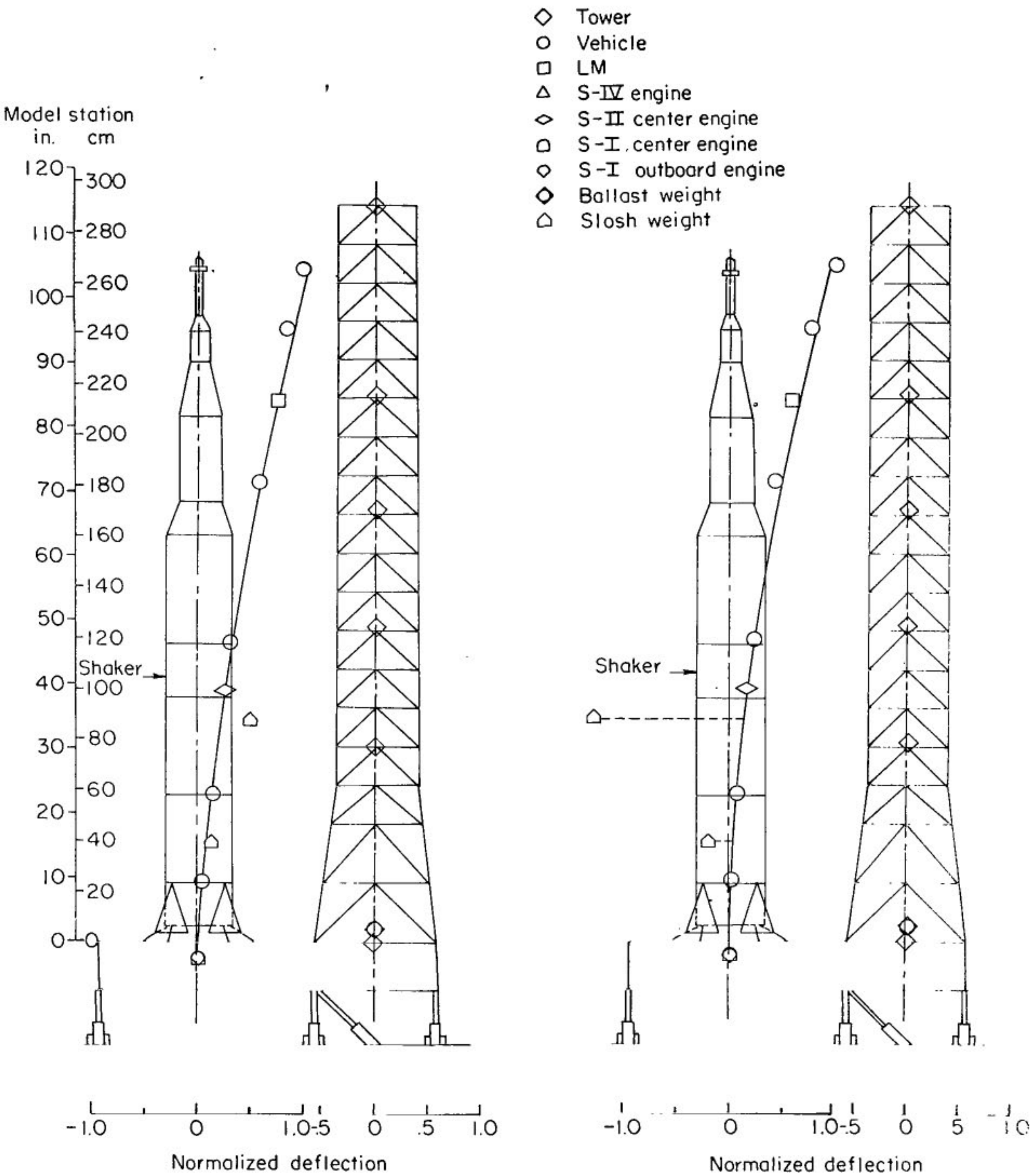


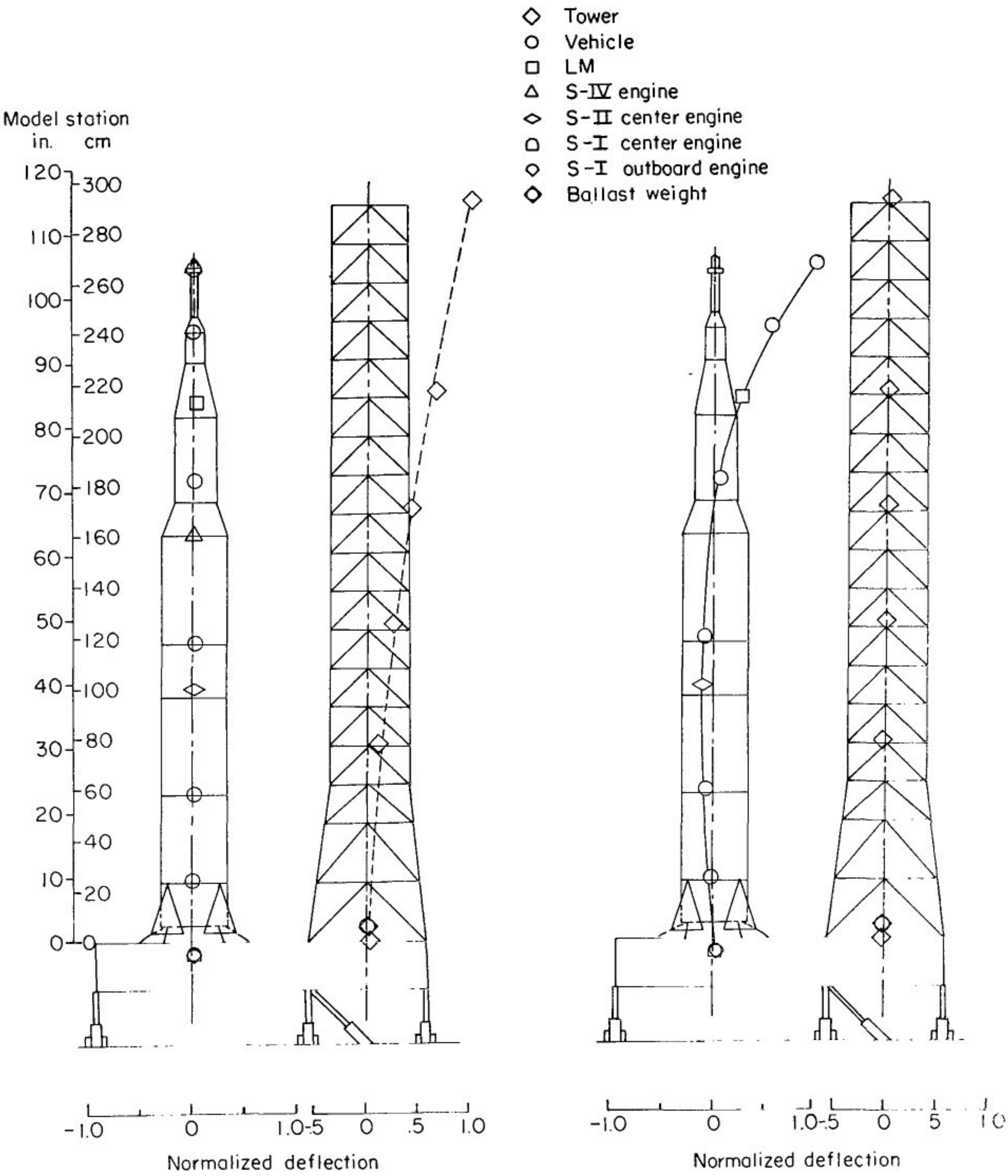
Figure 24.- Normalized frequency responses measured at tip of the fueled Saturn V model and at tip of the tower with the shaker oriented to apply force in x-direction.



(a) First mode. f = 9.5 Hz; g_{MV} = 0.0137.

(b) Second mode. f = 12.9 Hz; g_{MV} = 0.008.

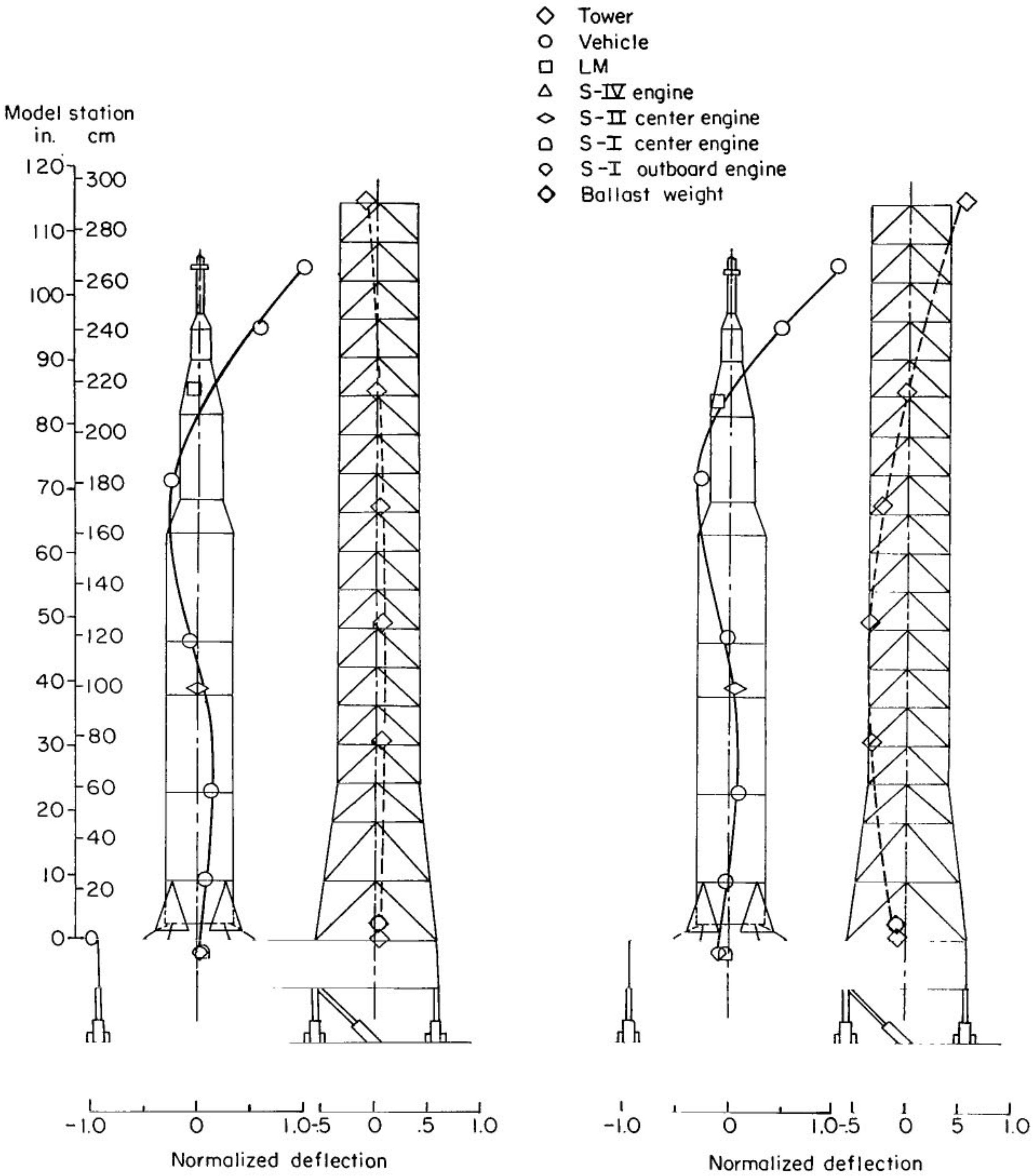
Figure 25.- Normalized mode shapes of 1/40-scale Saturn V-LUT configuration measured in x-direction with Saturn V model fueled.



(c) Third mode. f = 28.4 Hz; g_{MT} = 0.0017.

(d) Fourth mode. f = 34.9 Hz; g_{MV} = 0.0058.

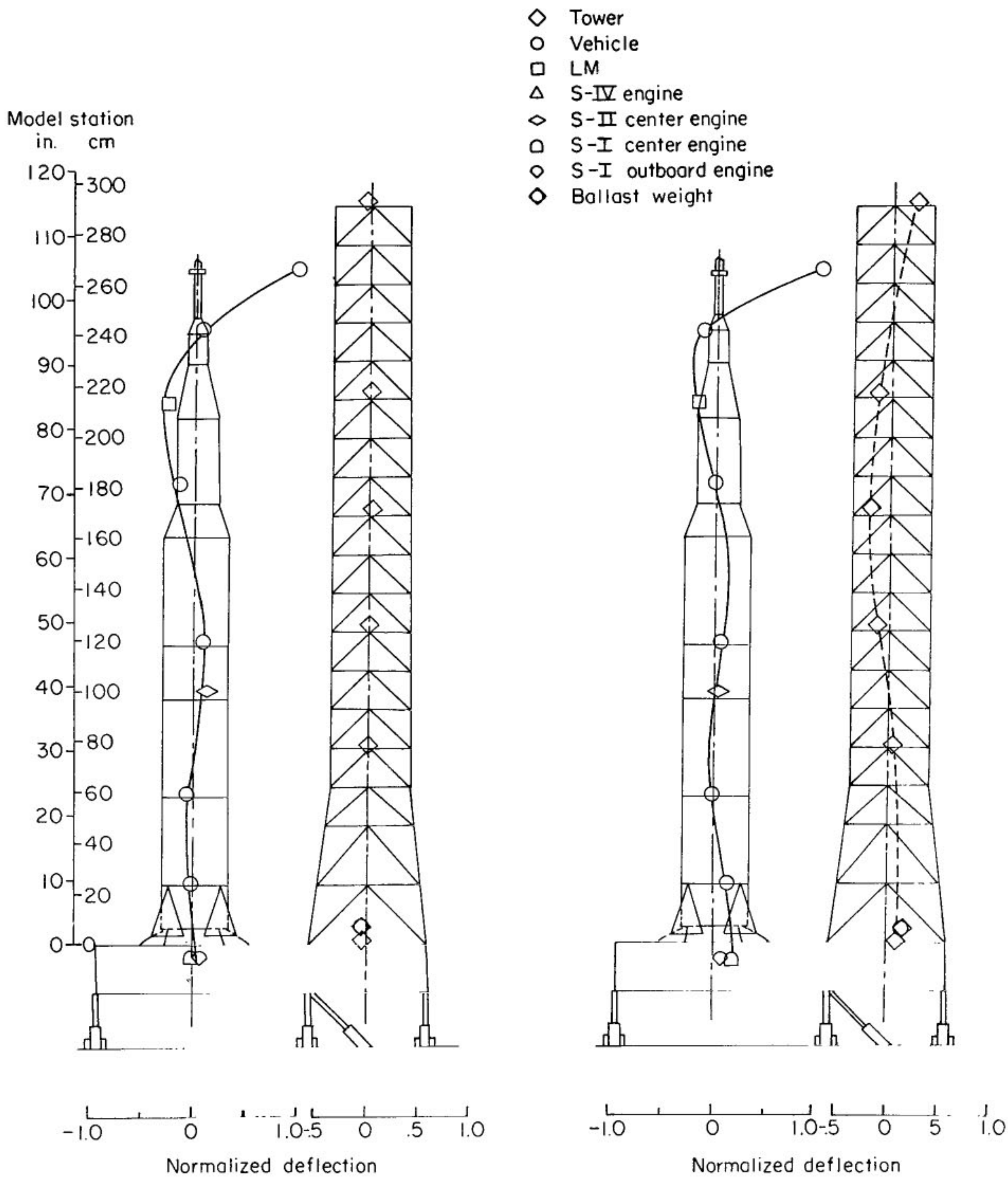
Figure 25.- Continued.



(e) Fifth mode. f = 61.9 Hz; g_{MV} = 0.0073.

(f) Sixth mode. f = 68.1 Hz; $g_{MV} = g_{MT}$ = 0.0033.

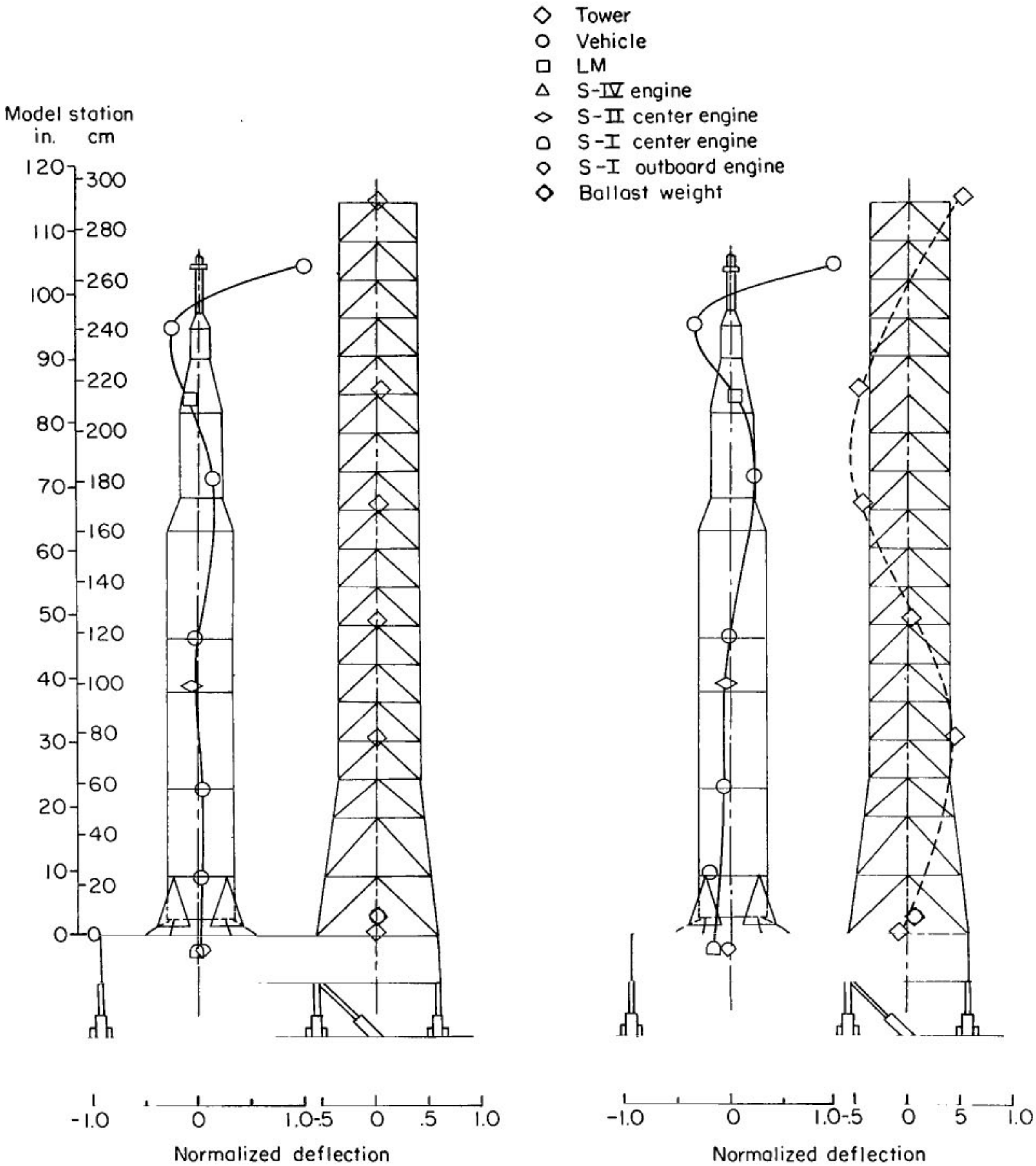
Figure 25.- Continued.



(g) Seventh mode. f = 98.1 Hz; g_{MV} = 0.0088.

(h) Eighth mode. f = 111.9 Hz; $g_{MV} = g_{MT}$ = 0.0055.

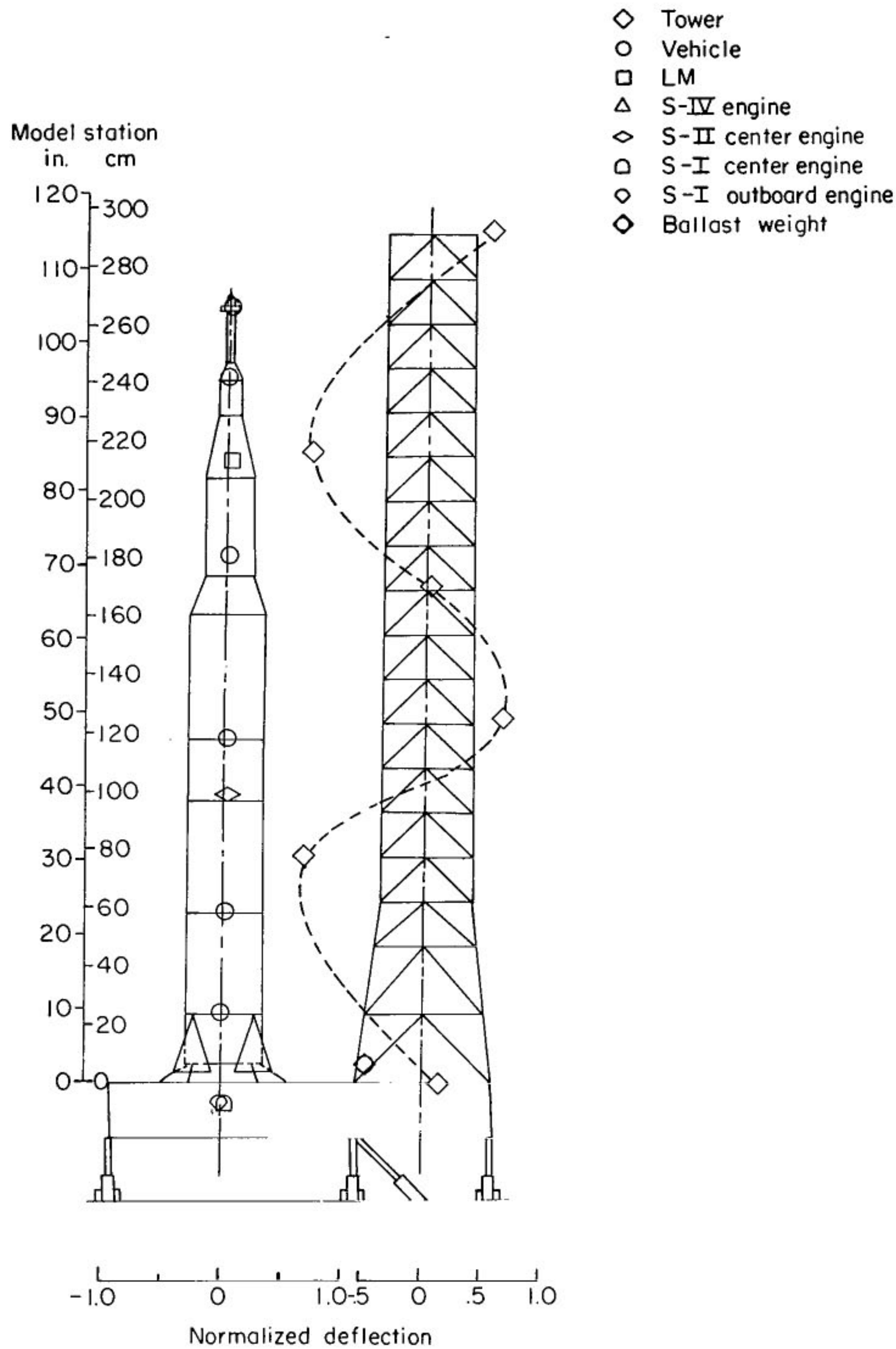
Figure 25.- Continued.



(i) Ninth mode. f = 127.7 Hz.

(j) Tenth mode. f = 140.5 Hz; g_{MT} = 0.0052.

Figure 25.- Continued.



(k) Eleventh mode. f = 215.1 Hz.

Figure 25.- Concluded.

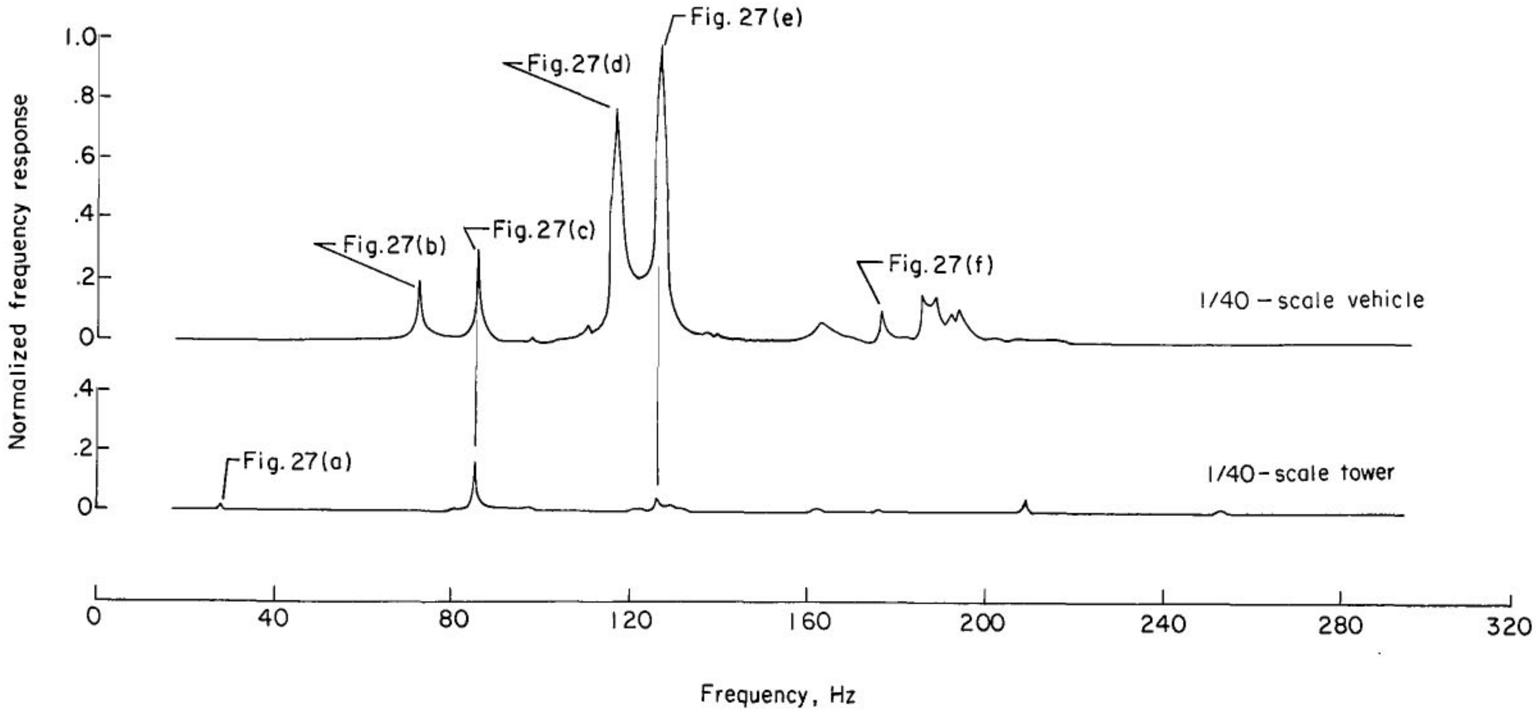
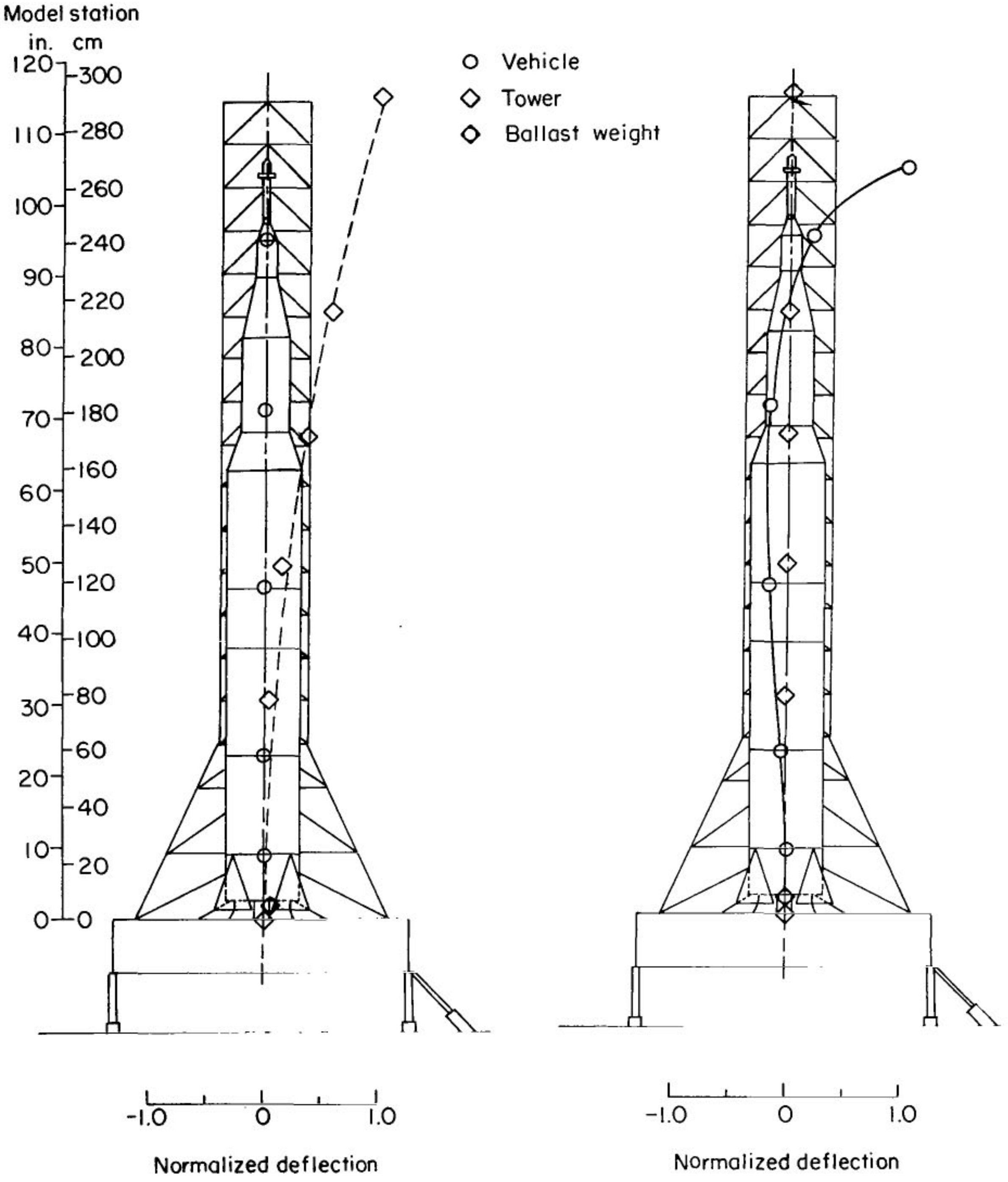


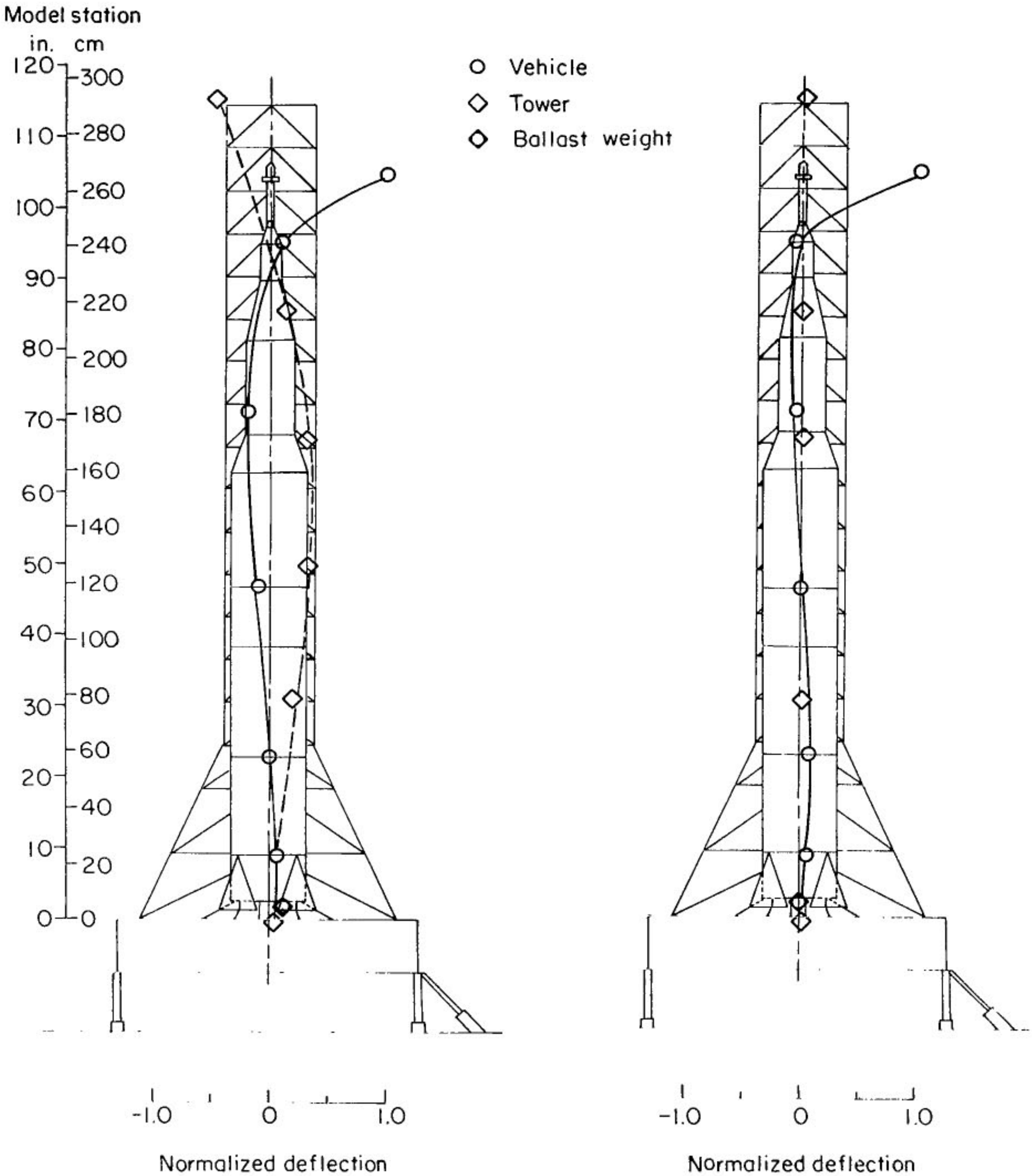
Figure 26.- Normalized frequency responses measured at tip of the unfueled Saturn V model and at tip of the tower with the shaker oriented to apply force in y-direction.



(a) First mode. f = 28.2 Hz; g_{MT} = 0.0013.

(b) Second mode. f = 72.1 Hz; g_{MV} = 0.0092.

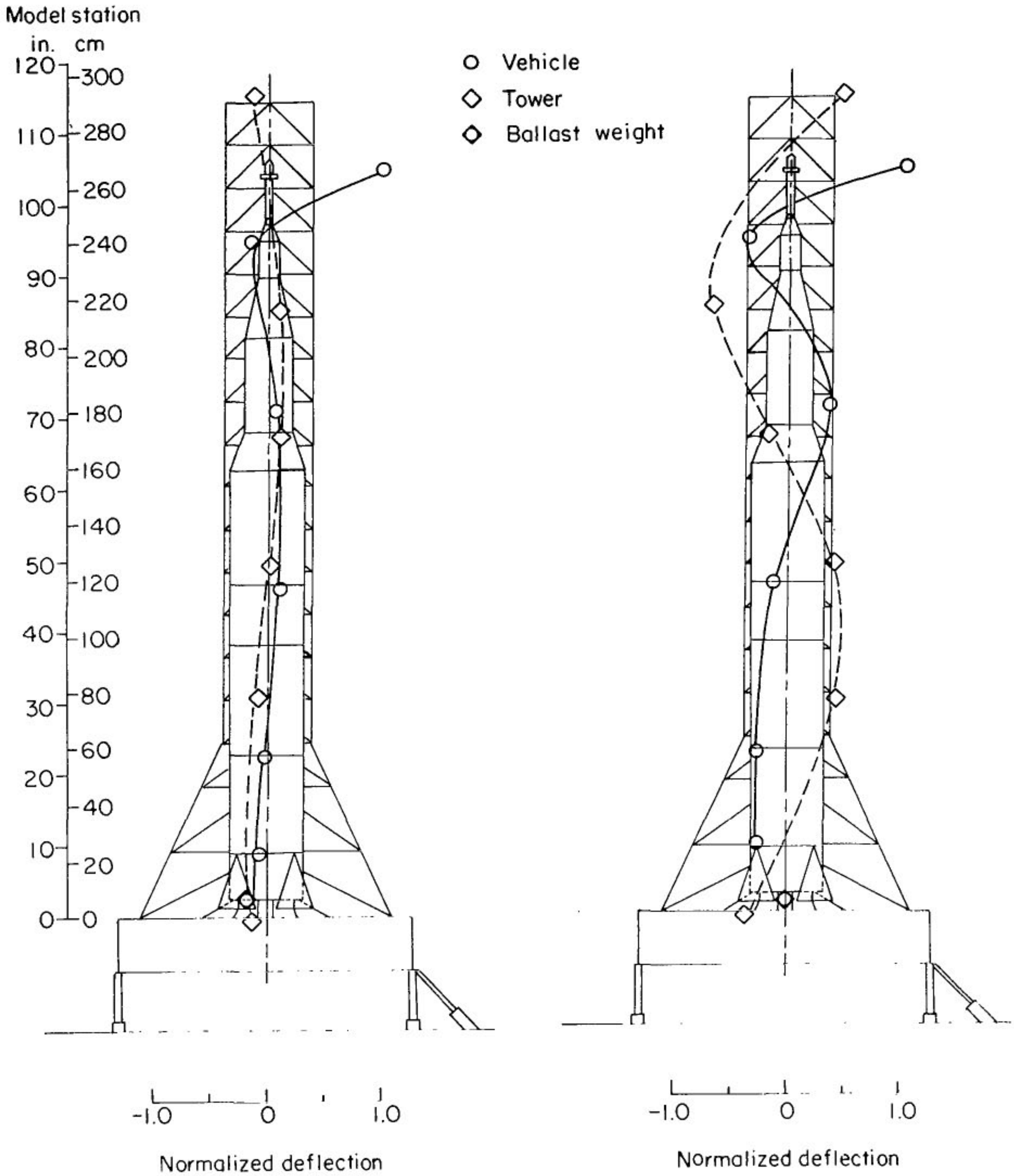
Figure 27.- Normalized mode shapes of 1/40-scale Saturn V-LUT configuration measured in y-direction with Saturn V model unfueled.



(c) Third mode. f = 85.3 Hz; g_{MT} = 0.0087.

(d) Fourth mode. f = 113.3 Hz.

Figure 27.- Continued.



(e) Fifth mode. f = 124.0 Hz; $g_{MV} = 0.0047$, $g_{MT} = 0.0058$.

(f) Seventh mode. f = 175.1 Hz; $g_{MV} = g_{MT} = 0.0011$.

Figure 27.- Concluded.

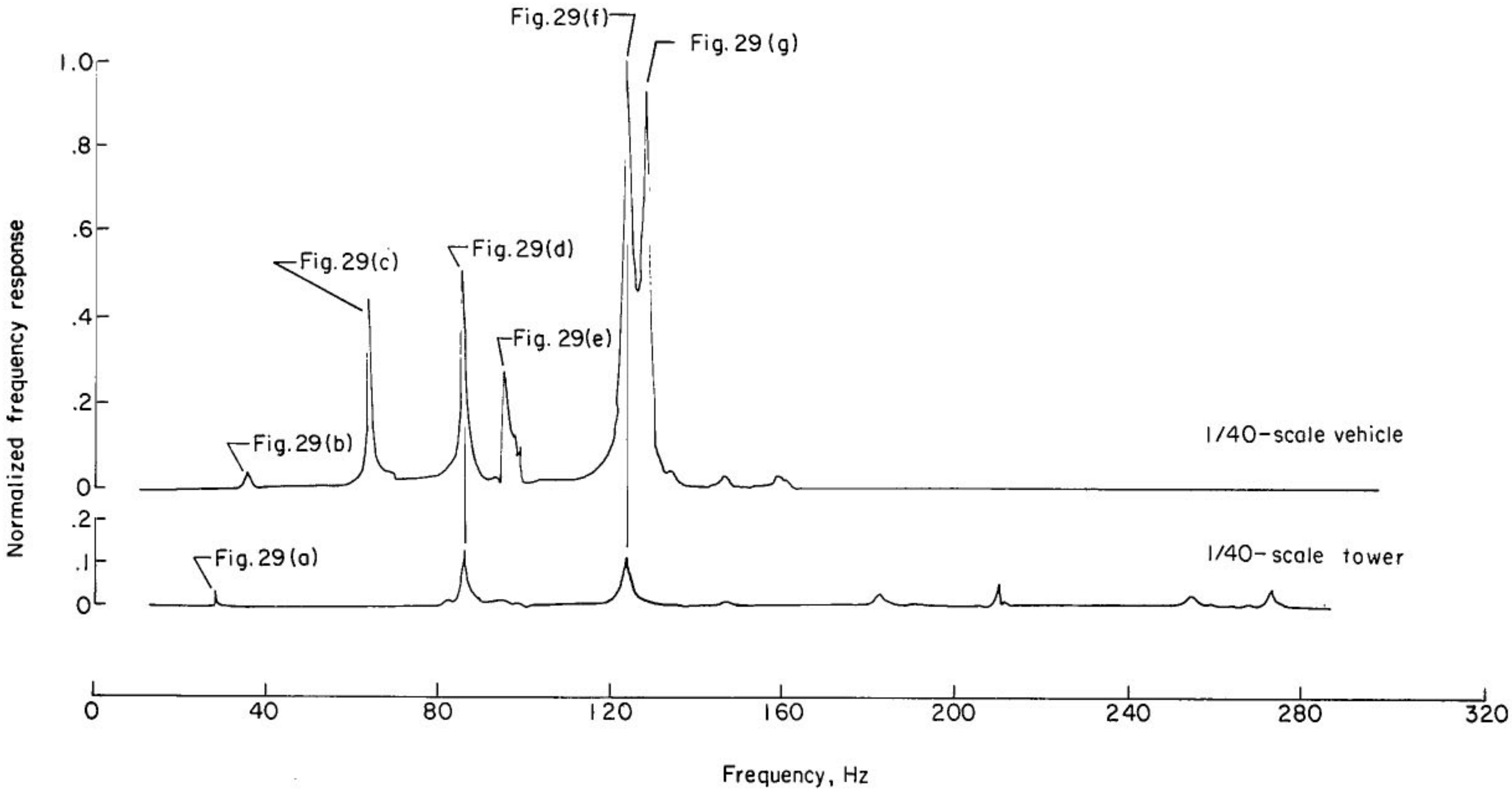
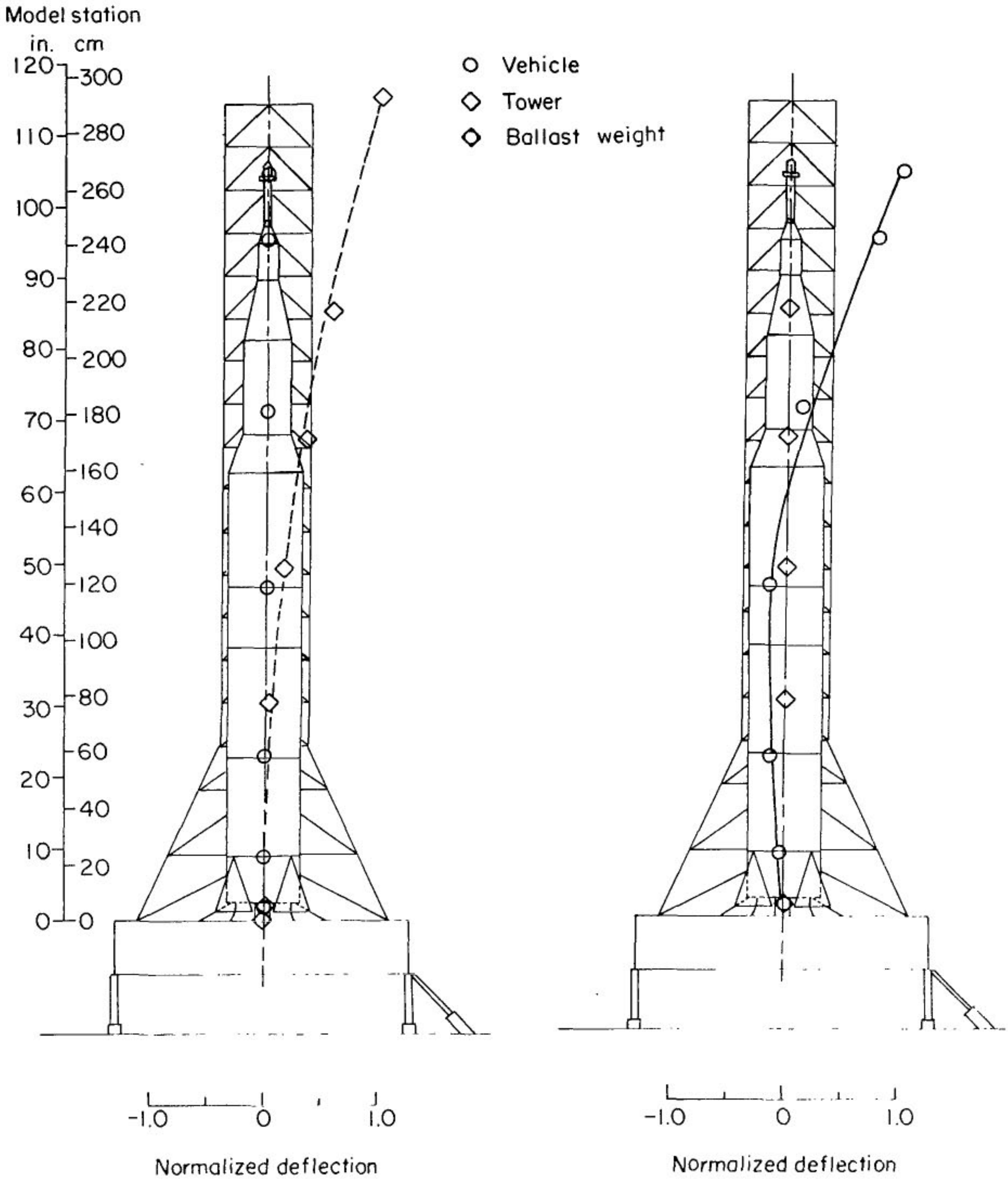


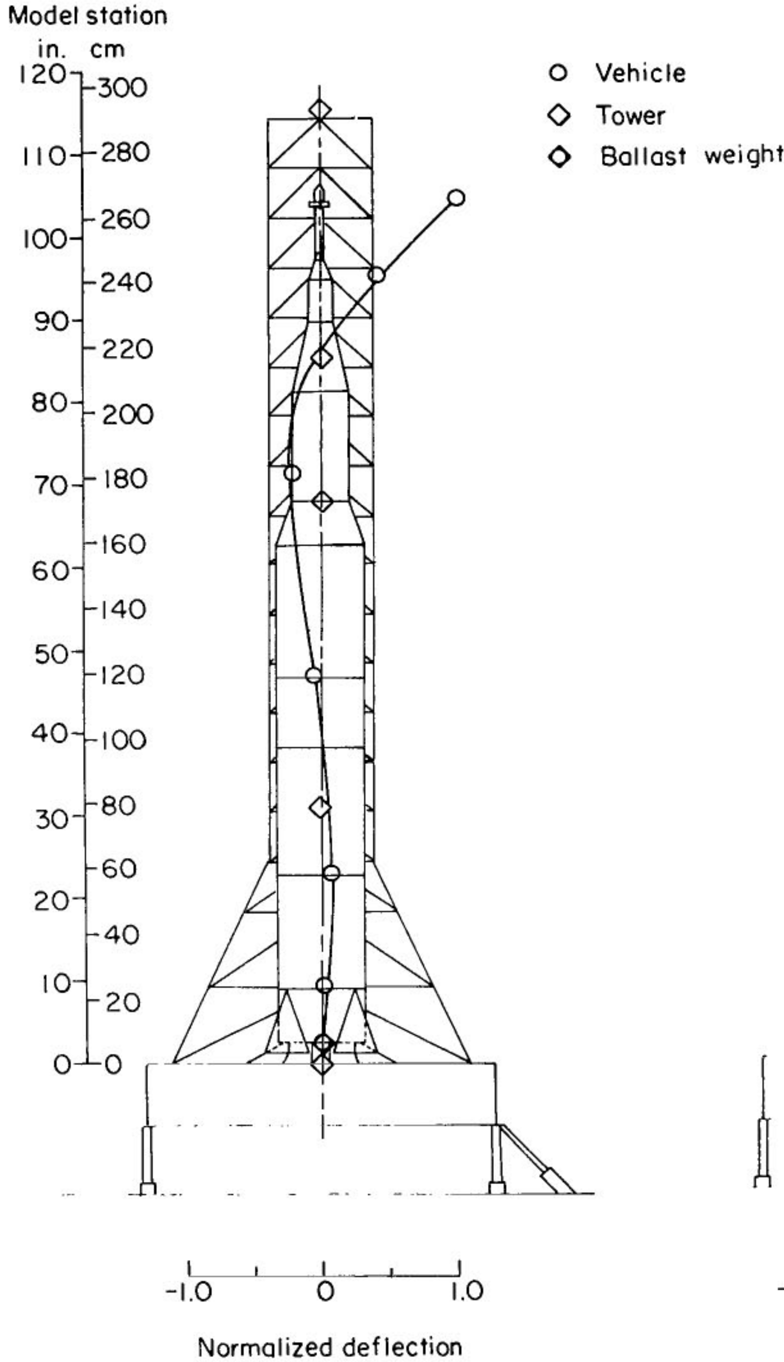
Figure 28.- Normalized frequency responses measured at tip of the fueled Saturn V model and at tip of the tower with the shaker oriented to apply force in y-direction.



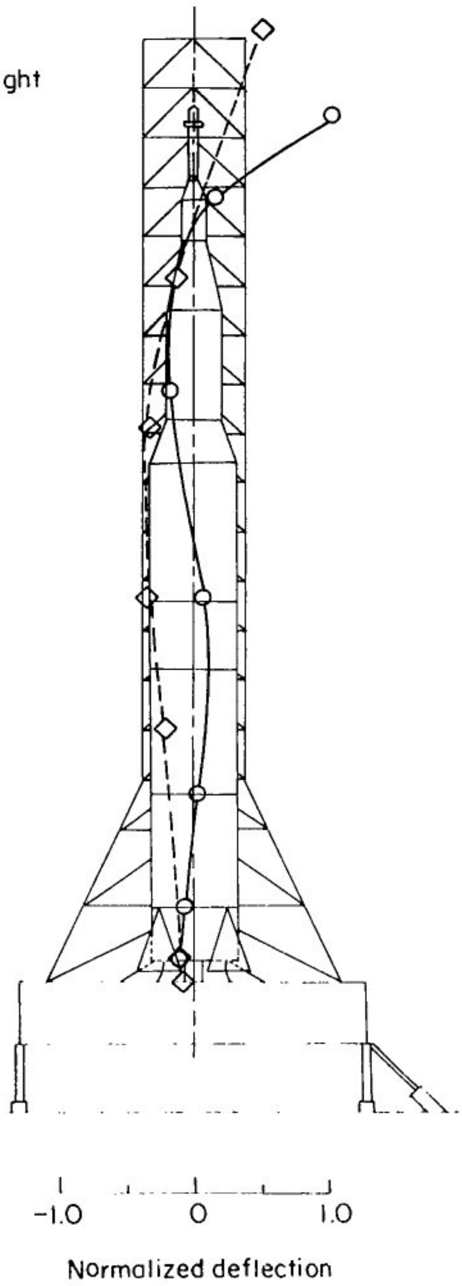
(a) First mode. f = 28.4 Hz; g_{MT} = 0.0013.

(b) Second mode. f = 35.0 Hz.

Figure 29.- Normalized mode shapes of 1/40-scale Saturn V-LUT configuration measured in y-direction with Saturn V model fueled.

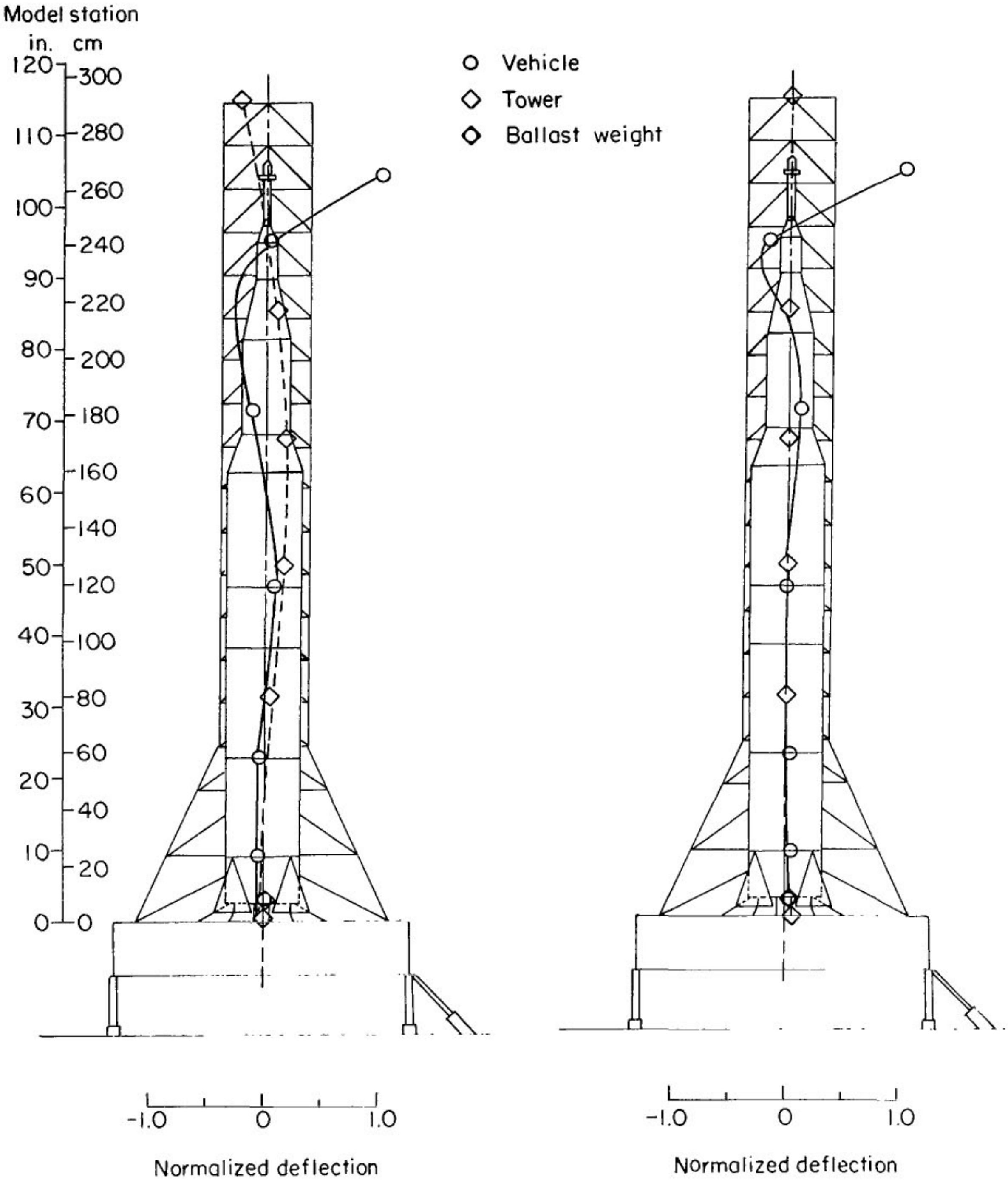


(c) Third mode. f = 62.9 Hz; g_{MV} = 0.0065.



(d) Fourth mode. f = 85.8 Hz; $g_{MV} = g_{MT}$ = 0.0037.

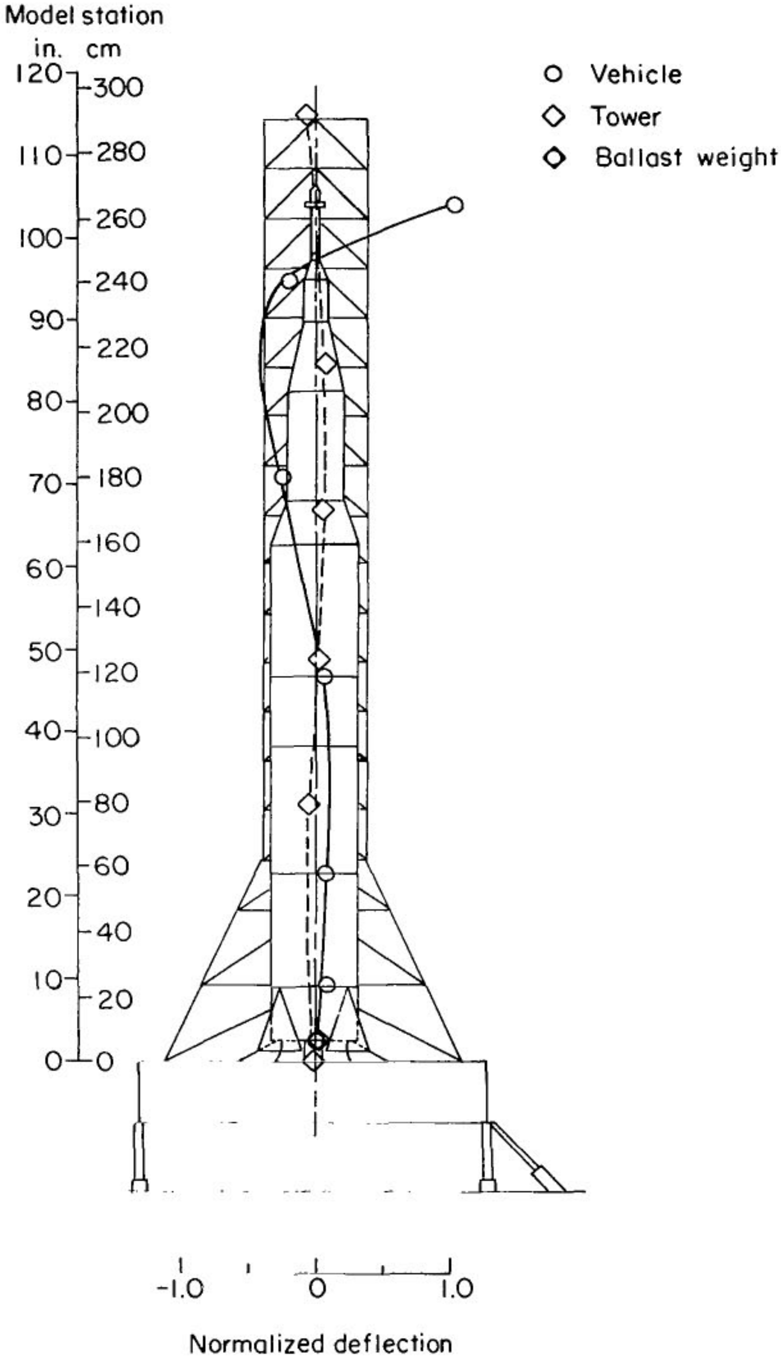
Figure 29.- Continued.



(e) Fifth mode. f = 97.1 Hz; g_{MV} = 0.0045.

(f) Sixth mode. f = 122.3 Hz.

Figure 29.- Continued.



(g) Seventh mode. f = 128.0 Hz.

Figure 29.- Concluded.

"The aeronautical and space activities of the United States shall be conducted so as to contribute . . . to the expansion of human knowledge of phenomena in the atmosphere and space. The Administration shall provide for the widest practicable and appropriate dissemination of information concerning its activities and the results thereof."

— NATIONAL AERONAUTICS AND SPACE ACT OF 1958

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